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Workload of the VTS Sector Operator and Implications for Task Design

U.S. Coast Guard
Research and Development Center
1082 Shennecossertt Road
Groton, CT 06340-6096

and

Naval Submarine
Medical Research Laboratory
Groton, CT 06349-5900

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G. T. Gunther
Technical Director, Acting
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

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16. Abstract

This study identifies the factors determining the VTS sector operator's workload and recommends the most appropriate use of automation to manage that workload. Investigations were conducted at VTS New York (Governors Island) and at VTS Puget Sound (Seattle, WA). The primary tasks, as measured at both sites, were radio communciations with traffic, the manual recording of vessel information and track history on cards, and the monitoring of traffic by radar. Analyses found that the primary determiner of the workload of these primary tasks was the number of participating vessels monitored by one operator and the amount of associated radio communications.

The findings support the recommendation of a "dynamic" sector to manage workload: that is, an automated system that could keep track of the number of vessels per sector and suggest an early hand-off point from a more busy to a less busy sector or, alternatively, a temporary split of a sector. Additional recommendations include the automation of some vessel communciations and the operator-friendly automation of vessel information and tracking. The study identified the vulnerability to high workload of operator-initiated traffic advisories and radar monitoring and recommends automation to assist these functions.

The report also includes a brief description of an examination of the VTS Upgrade, an automated console installed at VTS New York in late August 1994, and suggestions for its improvement based on the findings of this study.

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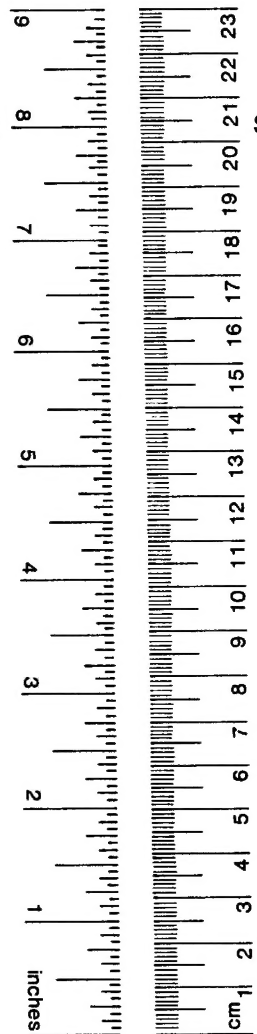
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

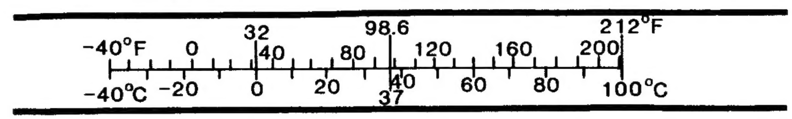
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



WORKLOAD OF THE VTS SECTOR OPERATOR AND IMPLICATIONS FOR TASK DESIGN

EXECUTIVE SUMMARY

INTRODUCTION

The U.S. Coast Guard provides Vessel Traffic Service (VTS) in major ports to facilitate the safe, effective, and efficient use of waterways. Traditionally, VTS has served this function by monitoring the vessel's progress through the area, creating and maintaining a record of this progress, and communicating with the master/pilot, providing information about waterway conditions and about other traffic as it is needed. Now, increasing concern for the protection of the environment means that additional ports and additional users are presenting demands for additional information and services. At the same time, new technologies offer the possibility both of increasing the quality of the information provided to VTS users and of managing the workload of the VTS watchstander. The purpose of this study was to determine the factors currently influencing the VTS watchstander's workload in order to provide recommendations on possible re-design of tasks and on the best use of technology to support the VTS watchstander, and, ultimately, the waterway user.

OBJECTIVES

The primary objective of this study was to identify and quantify the principal factors affecting the workload of the VTS watchstander. The study was designed to support two needs: a) to provide an understanding of the effects of harbor sector characteristics and of number of participating vessels, as a means to manage the VTS operator workload, and b) to provide an understanding of the effects of task and equipment as a means to support the design and introduction of increased automation. The scope of the study was limited to an investigation of the real-time operator-in-the-loop at the major, high-workload positions.

TECHNICAL APPROACH

The sector operator's task was examined in the operational setting, at VTS New York and at VTS Puget Sound. The measures taken included: frequency counts of operator activities, recordings of the operator communications with vessels, and operator questionnaires, which included ratings of the subjective workload for different work sessions.

FINDINGS FROM VTS NEW YORK AND VTS PUGET SOUND

VTS New York's Area of Responsibility is small and densely-trafficked with relatively complete radar and radio coverage.

The primary data, observed frequencies of operator activities, showed that the high-frequency activities were: communicating with vessels, working with vessel data cards (VDCs), and monitoring the radar. There were differences between the busier Upper Bay Sector (including Ambrose Channel) and the less busy Mariners Harbor (Newark Bay) in the frequency of these activities and in subjective ratings of workload. Activity level and subjective workload were found to be affected primarily by the number of participating vessels monitored in a unit of time by a single operator, rather than by sector area, total high volume mileage, or the density of vessels per track mile.

VTS Puget Sound's Area of Responsibility is characterized by a very much larger area, heterogeneity of traffic density over that area, less complete radar coverage, and less effective radio coverage. High frequency activities were similar to those observed at VTS New York: communicating with participating vessels, working with VDCs, and monitoring radar. The Puget Sound South Sector (including the Deep South Sector) had, on average, twice the number of participating vessels of any other sector, including those in New York. Correspondingly, it showed greater frequencies of communicating with vessels and working with VDCs, and higher ratings of subjective workload. This finding in Puget Sound reinforces the New York finding that **the number of participating vessels monitored in a unit of time by a single operator is the major determiner of activities and of subjective workload.**

At both VTSs, when there was a large number of participating vessels, there was an increase in responding to vessel-initiated communications and to the associated "working with VDCs." Radar monitoring did not increase consistently with number of vessels and, in some cases, decreased. When the number of vessels is large, operator activities compete for the operator's time, and radar monitoring tends to be an activity that is minimized during times of high traffic volume.

IMPLICATIONS FOR THE USE OF AUTOMATION IN TASK DESIGN

A major concern for both the near term and long term development of VTS is the best use of automation or technology to manage and moderate the workload of the VTS operator and to improve the quality of the service to the primary customer, the mariner. The study findings have implications for such changes in task design.

Since the primary determiner of workload is the number of participating vessels, an automated system that keeps track of the number of vessels per sector and recommends an early hand-off point from a more busy to a less busy sector would be a powerful management tool. In other words, the geographic boundaries of

the "sector" could be dynamic. When the disparity in number of vessels is too great to be remedied by varying the boundaries, an automated system might recommend the location of a temporary split of the busy sector to allow an additional operator to take over some of the work.

Vessel-initiated radio transmissions were closely related to the number of vessels and had major effects on the sector operator's subjective ratings of workload. The effects on the operator are apparently the result of the requirement to respond quickly to vessel transmissions, with little control over timing. The findings suggest that the reduction in vessel transmissions by automation would not only reduce the operator's subjective workload, but also would allow more time for other important operator activities. Automatic Dependent Surveillance (ADS) technology has introduced the possibility that information might be automatically transmitted from vessel to VTS without operator participation. Such an approach, planned for VTS 2000, should reduce the workload of the sector operator.

Manually creating and maintaining the vessel information using VDCs proved to be a major contributor to the sector operator's workload. **The findings of the present study suggest that the effective automation of the vessel information function is probably the simplest and most straight-forward mechanism for reducing the sector operator's workload and improving performance within the present general concept of VTS.**

Operator-initiated radio transmissions had less of an effect on ratings of subjective workload than did vessel-initiated transmissions, apparently because operators were able to control the timing and content of self-initiated communications. If such transmissions are reduced when workload is high, this represents a reduction in service to the mariner. Automation of this activity or some of its components is a possibility. For example, routine Operational Notices could be automatically broadcast to vessels in an area without the immediate involvement of the operator, leaving time for communications that must be customized to a particular vessel.

Radar monitoring had very little effect on ratings of subjective workload. Presumably, this was because its timing is much more under the control of the operator than are other activities and because it is likely to be limited when the workload is high. Such limitation is undesirable, assuming that radar monitoring is a primary component of traffic monitoring and of the formulation of advisories. In the short term, the simplest mechanism to improve radar monitoring would be the automation of the activities less under the control of the operator, such as vessel-initiated transmissions and creating and

maintaining vessel information. Operator-initiated radar monitoring should be the indirect beneficiary.

IMPLICATIONS FOR THE VTS NEW YORK UPGRADE

The VTS Upgrade, installed in New York in late August of 1994, is an integration of remote sensors, database systems, and operator displays. Observations of operator activities using the Upgrade were made during the final acceptance testing. At that time the operators were fully trained on the system but inexperienced in its use. The findings provide an indication of the principal strengths and weaknesses of the system.

The primary activity of vessel communications was done as it had been done on the earlier baseline system. Its relative percentage of operator activities remained the same, 14 percent of the total.

A major feature of the Upgrade is the automation of the creation and maintenance of vessel information. This is done by accessing information for each participating vessel in an existing database and then automatically tracking that vessel by radar or by "Estimated Positioning." Despite this substantial change from manually recording information on VDCs, the relative percentage of operator activities for this function remained unchanged at 23 percent in each case. This is a disappointing result and a missed opportunity. Sector operators identified specific features of the Upgrade that should be modified to improve the vessel information function and to reduce its workload.

The combined vessel tracking/radar monitoring function was 37 percent of operator actions using the Upgrade, compared to 24 percent for radar monitoring using the old system. This increase was found to be the result of difficulties with the radar function that created a new need to monitor and adjust the tracking feature, taking away from time spent monitoring the traffic situation. Some portion of the difficulties with vessel tracking may be temporary. **A smoothly operating radar function is central to the effective use of the Upgrade system and this function requires further evaluation and development.**

The Upgrade did not support the real-time operator-in-the-loop as well as is needed. The effects of this inadequate support were an increase in the operator's workload for some activities and missed opportunities to decrease workload for other activities. Greater concern needs to be given to the human factors requirements of system development, both for the Upgrade and for VTS 2000.

SUMMARY OF RECOMMENDATIONS

The study findings support the following recommendations. They are repeated here from the Conclusions section where they are discussed more fully.

Application of Human Factors Principles

- Any planning, design, or evaluation of the VTS operator's task should have as an objective an effective, but not excessive, use of the individual's time, attention, and cognitive capacity. After any changes are made to the operator's responsibilities, the effects should be re-evaluated.

Managing Responses to Harbor or Sector Conditions

- When a new system is in place with the capability of recording and plotting vessel transits, the issue of "places of track convergence" (or congested areas) should be re-examined. Plotted overlays of tracks monitored by an operator in a unit of time will identify those places. Sector boundaries should be located to distribute these places among the operators and these sector configurations should be evaluated for their effects on workload and situational awareness. The record keeping capabilities of the new system will allow further investigation of other harbor factors as well.

- Any increase in number of participating vessels in a harbor should be accompanied by an evaluation of the effects of these increases on the sector operator's workload. If the effect is a substantial increase, changes in task design should be introduced to offset the increase. Options are changes in sector size, re-distribution of some activities to other individuals, or automation of some activities.

- Increases in responsibility for the VTS sector operator, such as increase in sector size or in number of participating vessels, should be carefully balanced against the demands imposed by task or equipment design.

- With harbor conditions and with task and equipment design similar to that observed in NY and PS, an attempt should be made to keep the number of vessels monitored by a single operator not much higher than 14 in a half hour. When the Upgrade is well established in NY and/or PS, workload should be re-evaluated with that new equipment. New activity and subjective workload levels can be evaluated by comparison with that measured with the baseline equipment and the baseline 14 vessels.

Increases in Level of Automation

- Among the operator's activities, the highest priority for automation or re-distribution should be given to responding to vessel-initiated transmissions and to keeping vessel transit records.

- Consideration should be given to automatic broadcasting of the more routine operational notices and advisories.

- Consideration should be given, but with a lower priority, to the automation of some components of radar monitoring. Examples are alarms when acquired targets approach each other or approach designated dangers.

- The design of new equipment should include a "dynamic sector" that would recommend or allow changes in sector boundaries. Boundary considerations should be traffic density, places of track convergence, and radio channel boundaries.

- Given the very central role of communications in the VTS function, continuous attention should be given to the communication needs of the VTS operator and of the mariner, and to the developing technologies available to serve those needs.

- For VTSPS, with its large area and relatively poor radio transmissions, consideration should be given to an automatic process to find the best site to communicate with each vessel.

- A high priority should be given to correcting the functioning of the Upgrade's automatic tracking system

- With the installation of the Upgrade, the VTS operator's use of this new system should be evaluated for "situational awareness" as well as workload. VTSPS, with its large area to be monitored, has a special need for such an evaluation.

- Physical layout of the new VTCs should be planned and evaluated with consideration of both necessary physical proximity and protection from noise and disturbance.

TABLE OF CONTENTS

			Page
1.0	INTRODUCTION		1
	1.1	EXAMINATION OF THE VTS SECTOR OPERATOR'S WORKLOAD	1
	1.2	BACKGROUND	1
		1.2.1 U.S. Coast Guard Human Factors Plan	1
		1.2.2 U.S. Coast Guard's On-going Development of Vessel Traffic Systems	1
	1.3	OBJECTIVES AND SCOPE	2
	1.4	A "MODEL" OF THE SECTOR OPERATOR'S TASK	3
	1.5	DEFINITION AND MEASUREMENT OF WORKLOAD	4
	1.6	ORGANIZATION OF THIS REPORT	5
2.0	TECHNICAL APPROACH		6
	2.1	OBJECTIVE MEASURES	6
	2.2	SUBJECTIVE OPERATOR WORKLOAD (OWL) MEASURES	7
	2.3	REPRESENTATIVE VESSEL TRAFFIC CENTERS	8
		2.3.1 VTS New York, Governors Island, New York	9
		2.3.2 VTS Puget Sound, Seattle, WA	9
		2.3.3 The VTS Sector Operator's Task	11
3.0	INVESTIGATION AT VTS NEW YORK		13
	3.1	TASK COMPONENTS AND SECTOR DIFFERENCES	13
		3.1.1 Method	13
		3.1.2 Results and Discussion	14
	3.2	SECTOR OPERATORS' SUBJECTIVE REPORTS	16
		3.2.1 Method for Subjective Measures and Questionnaire	16
		3.2.2 Results of Subjective Measures	16
	3.3	ANALYSIS OF SECTOR OPERATOR PERFORMANCE	16
		3.3.1 Summary Correlation Matrix	16
		3.3.2 Criticality of Measures to the Sector Operator's Task	17
	3.4	SUMMARY AND CONCLUSIONS FOR VTSNY	21
4.0	INVESTIGATION AT VTS PUGET SOUND		22
	4.1	TASK COMPONENTS AND SECTOR DIFFERENCES	22
		4.1.1 Method	22
		4.1.2 Results and Discussion	22
	4.2	SECTOR OPERATORS' SUBJECTIVE REPORTS	24
		4.2.1 Method for Subjective Measures and Questionnaire	24
		4.2.2 Results of Subjective Measures	25
	4.3	ANALYSIS OF SECTOR OPERATOR PERFORMANCE	27
		4.3.1 Summary Correlation Matrix	27
		4.3.2 Criticality of Measures to the Sector Operator's Task	29
	4.4	SUMMARY AND CONCLUSIONS FOR VTS PUGET SOUND	29

5.0 MAJOR FINDINGS AND THEIR IMPLICATIONS 32
5.1 MAJOR VARIABLES AND OBSERVED SECTOR PATTERNS . . . 32
5.2 PATH ANALYSIS OF THE SECTOR OPERATOR'S TASK USING VTS NEW YORK DATA 34
5.3 PATH ANALYSIS OF THE SECTOR OPERATOR'S TASK USING VTS PUGET SOUND DATA 36
5.4 SUMMARY OF MAJOR FINDINGS AND THEIR IMPLICATIONS . 38

6.0 CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS 41
6.1 OBSERVED BEHAVIOR OF THE VTS SECTOR OPERATOR AND ITS IMPLICATIONS 41
6.2 HARBOR FACTORS AS DETERMINERS OF THE SECTOR OPERATOR'S WORKLOAD 42
6.3 TASK ACTIVITIES AS DETERMINERS OF THE SECTOR OPERATOR'S WORKLOAD 43
6.4 IMPLICATIONS FOR VTS ISSUES 45
6.5 OBSERVATIONS ON ADDITIONAL VTS ISSUES 49
6.6 SUMMARY OF CONCLUSIONS 52

7.0 A QUICK LOOK AT VTS NEW YORK'S USE OF THE UPGRADE . . . 54
7.1 INTRODUCTION AND OBJECTIVES 54
7.2 APPROACH 55
7.3 PRINCIPAL FINDINGS 55
7.3.1 Observational Data on Early Use of the Upgrade 55
7.3.2 Comparison to Baseline VTS New York Operation 57
7.4 RESULTS OF THE OPERATOR QUESTIONNAIRE 59
7.4.1 Operator's Subjective Rating of Workload . . 59
7.4.2 Contributors to Workload 59
7.4.3 Summary of Operator Comments 62
7.5 CONCLUSIONS ON THE EARLY USE OF THE UPGRADE 64
7.5.1 Potential Contributions of Integration and Automation 64
7.5.2 Effectiveness of Vessel Information Functions 64
7.5.3 Effectiveness of Vessel Tracking 64

REFERENCES 66

LIST OF FIGURES

Figure | Page

Figure 3-1. Unidimensional scaling results for VTS New York variables 20

Figure 4-1. Unidimensional scaling results for VTS Puget Sound variables 30

Figure 5-1. Path analysis of VTS New York data 35

Figure 5-2. Path analysis of VTS Puget Sound data 37

LIST OF TABLES

Table		Page
Table 3-1	*VTS New York Measures*	15
Table 3-2	*Selected Correlations from VTS New York*	18
Table 4-1	*VTS Puget Sound Measures*	23
Table 4-2	*Subjective Ratings on NASA Task Load Index*	25
Table 4-3	*Summary of Reported Contributors to Subjective Workload*	26
Table 4-4	*Selected Correlations from VTS Puget Sound*	28
Table 5-1	*Summary of Major Variables over Five Sectors*	33
Table 7-1	*VTS New York Upgrade Measures*	56
Table 7-2	*Selected Comparisons of Percentage of Total Activities for Baseline and Upgrade*	57
Table 7-3	*Summary of Rated Contributors to Workload*	61

1.0 INTRODUCTION

1.1 EXAMINATION OF THE VTS SECTOR OPERATOR'S WORKLOAD

The U.S. Coast Guard provides Vessel Traffic Service (VTS) in major ports to facilitate the safe, effective, and efficient use of waterways. Traditionally, VTS has served this function by monitoring the vessel's progress through the area, creating and maintaining a record of this progress, and communicating with the master/pilot, providing information about waterway conditions and about other traffic as it is needed. Now, increasing concern for the protection of the environment means that additional ports and additional users are presenting demands for additional information and services. At the same time, new technologies offer the possibility both of increasing the quality of the information provided to VTS users and of managing the workload of the VTS sector operator. The purpose of this study was to determine the factors currently influencing the VTS operator's workload in order to provide recommendations on possible re-design of tasks and on the best use of technology to support the VTS operator, and, ultimately, the waterway user.

1.2 BACKGROUND

1.2.1 U.S. Coast Guard Human Factors Plan

In 1992, a U.S. Coast Guard planning effort for Human Factors research (Sanquist, Lee, Mandler, and Rothblum, 1993) identified two concerns within the VTS community. The first was the level of workload that VTS operators experience in monitoring traffic. This study was a specific response to that concern. The second was the communications between VTS and the mariner. Difficulties in communications for VTS include unresponsiveness on the part of the vessel and the difficulty of identifying the vessel doing the communicating. Difficulties for the mariner include the intrusion of VTS during critical vessel maneuvers. Because communicating with vessels is a major activity of the VTS operator, the present study provides a context for further analysis of the communication problem, planned for Fiscal Year 1996.

1.2.2 U.S. Coast Guard's On-going Development of Vessel Traffic Systems

The U.S. Coast Guard has done considerable planning and development of VTS in recent years. The Port Needs Study (Maio, Ricci, Rossetti, Schwenk, and Liu, 1991) documented the benefits and costs of potential VTS in additional deep draft ports and identified those ports where VTS would provide the greatest net benefit. The Mission Need Statement (U.S. Coast Guard, 29 May 1992) described enlarged functional capabilities envisioned for future VTS. The vision for future VTS is presented in the VTS

2000 Operational Concept (United States Coast Guard, July 1993). The latter re-affirms and continues the traditional VTS function of "providing accurate information to mariners to support their independent decision making." The vision for the future of U.S. Coast Guard VTS was discussed further in a recent paper for the International Association of Lighthouse Authorities (Rollison, 1994). At the present time a major procurement is underway to develop and install the new systems, VTS 2000, in a number of additional ports. The present study is intended to contribute to the planning process.

To enhance the capabilities of existing VTSs, the U.S. Coast Guard is in the process of installing the VTS Upgrade, incorporating some of the features desired for VTS 2000. The Upgrade is the integration of remote sensors, data base systems, and operator displays. In human factors terms, the operator works with one console on which he or she can control integrated radar and chart views of the waterway sector, video views, communications, and windows presenting vessel data. As of this writing in the autumn of 1994, the Upgrade has been installed at VTS New York and is operational. The study reported here included an examination of the sector operator's use of that system during the final testing and recommendations for possible improvements. When the New York installation is complete, the Upgrade is to be refined and installed at VTS Puget Sound.

1.3 OBJECTIVES AND SCOPE

The primary objective of the study was to identify and quantify the factors that determine the extent of the VTS sector operator's workload. The principal scope of investigation was the sector operator as the real-time operator-in-the-loop at the major, high workload positions. It is this sector operator who is most vulnerable to the vagaries of harbor and traffic conditions, most dependent on equipment and task design, and the primary contact of the principal VTS customer, the mariner in transit through the area.

During the planning and conduct of the study, the VTS community expressed many "human factors" or "workload" concerns. The following questions, closely related to the primary objective and to each other, were considered during the design of the study and during the data analysis. The relevance of the findings to these questions is discussed in Section 6. Additional issues, not directly considered in this study, are discussed with suggestions for further research.

1. From U.S. Coast Guard Headquarters (G-NVT): Traditionally, a "sector" was one radar site, one radar scope, and one operator. Now that digitized radar information, and other types of information, can be processed and presented in many ways, is

there a more effective definition of a "sector" or a more effective way of dividing the VTS responsibility among operators?

2. From several sources: What factors should be considered in apportioning responsibility among operators to achieve equality of workload? Can the appropriate responsibility for one operator be quantified within the scope of this study?

3. From the VTS development process, an ambitious question: How can technology or automation best be used to moderate the workload of the VTS sector operator and to increase the effectiveness of the service provided to the mariner?

4. From the VTS development process and from research efforts in Automatic Dependent Surveillance (ADS)(Radice, 1993): How can communication between VTS and the participating vessels be improved? And if it is now possible to automatically transmit a considerable amount of information between vessel and VTS, what kinds of information could be transmitted most productively?

5. From New York VTS: With the introduction of the Upgrade, there are plans to increase the Area of Responsibility (AOR) and the number of vessels required to participate. What effects can be expected on operator workload?

6. From Puget Sound VTS: Communications is a major part of the sector operator's task. In sections of the AOR, radio communications are difficult, necessitating searches through several radio sites. What effects are these difficulties having on workload?

1.4 A "MODEL" OF THE SECTOR OPERATOR'S TASK

A number of assumptions about the nature of the real-time operator-in-the loop process guided the design of the study and the analysis of the data. A brief summary of these follows.

1. An earlier study of the VTS watchstander (Devoe et al., 1979) divided the watchstander's tasks into three functions. *Monitoring* was keeping track of the traffic situation, by radio, radar, television, plotting tables, card racks, etc. *Information processing* was writing, keying, moving cards, calculating, etc. It also included mental activity involved in predicting the situation, mental activity that could not be distinguished from monitoring by an observer. *Communications* was speaking or listening on VHF radio, activities that were observable and recordable. This breakdown was adopted as a starting point for the present study.

2. A general view in the human factors literature is that the system operator has finite cognitive resources to bring to a task (Wickens, 1984). In a multi-task situation, those resources must

be distributed among the tasks by the operator using a strategy that is not always optimal. The distribution will affect the operator's performance and, therefore, has consequences for total system performance.

3. In the VTS operation, the operator's finite cognitive resources are distributed among task components. One aspect of this study's objective was to discover how the resources are distributed among task components under different operational and task design conditions. Such a description is difficult because the task components, like "monitoring" and "information processing" cannot be readily defined without overlap and because cognitive effort on any of these components is not readily observable by a researcher.

As the present study progressed, a different view of the sector operator's task developed. During the data collections for the study, activities were defined as relatively discrete observables: for example, looking at the radar, filling out vessel data cards (VDCs), communicating with vessels. Questionnaires were used to ask the operators about unobservable, cognitive components like "monitoring traffic" or "formulating advisories." During data analysis, a division was made between such obvious *information production* activities as filling out vessel data cards or plotting vessel tracks and more subtle *information use* in looking at radar or television scopes or reviewing vessel data cards. The latter was assumed to be the best indication of cognitive effort in monitoring the traffic situation or predicting the future situation. In this context, the short-term objective of computer-based automation is seen as assisting the operator in information production and freeing human cognitive capacity for monitoring and predicting the traffic situation.

1.5 DEFINITION AND MEASUREMENT OF WORKLOAD

"Workload" was defined in a VTS memo as "an increased level of vessel activity resulting in heightened operator concern, anxiety, and communications levels" (U.S. Coast Guard, 15 October 1992). Workload was quantified in that memo by listing the numbers of miles, radar sites, communication sites and frequencies, number of anchorages, ports, etc. in a given sector for an operator's attention. Also considered were the difficulties of conditions, users, or events to be expected in a sector. That memo provided important insight into the relevant issues in the planning of this data collection and analysis.

There is a considerable human factors literature on operator workload (OWL), reflecting the considerable concern from operational settings -- like VTS. Such concern is justified, based on a general finding of a relationship between workload and performance (Huey and Wickens, 1993; Lysaght et al., 1989). The

literature contains numerous definitions of workload, having to do with the objective amount of work to be done, the time available in which to do it, the subjective experience of the operator, etc. (Lysaght et al., 1989). The definitions of workload suggest methods of measurement (Wierwille and Eggemeier, 1993). The present study included both (objective) frequency counts of operator activity and (subjective) operator ratings of workload.

1.6 ORGANIZATION OF THIS REPORT

SECTION 2.0 TECHNICAL APPROACH provides a general overview of the assumptions and methods of the study.

SECTION 3.0 INVESTIGATION AT VTS NEW YORK describes the first investigation. The intention was not to investigate VTS New York (VTSNY) for its own sake, but to investigate the VTS process in a representative system. Section 3.0 very briefly describes operations at VTSNY, the specific conditions under which observations were made, the measures that were taken, and the analysis of those data. The results are presented and discussed.

SECTION 4.0 INVESTIGATION AT VTS PUGET SOUND describes the second investigation. The intention at VTS Puget Sound (VTSPS) was to extend the study to another system in order to test the generality of the findings and to increase the range of conditions examined. Section 4.0 very briefly describes operations at VTSPS, the specific conditions under which observations were made, the measures that were taken, and the analysis of those data. The results are presented and discussed.

SECTION 5.0 MAJOR FINDINGS AND THEIR IMPLICATIONS describes a final analysis of the major variables from both New York and Puget Sound.

SECTION 6.0 CONCLUSIONS AND IMPLICATIONS FOR TASK DESIGN discusses the overall findings and relates them to the U.S. Coast Guard's VTS workload-related concerns.

SECTION 7.0 A QUICK LOOK AT VTS NEW YORK'S USE OF THE UPGRADE describes an examination of the sector operator's use of the Upgrade during the final testing at VTS New York. This examination was meant both to test the generality of the earlier findings and to generate recommendations for potential changes to the system or to operations using the system.

2.0 TECHNICAL APPROACH

In order to design an effective study of VTS watchstander workload, various sources of information were examined. These included general human factors literature on workload, previous studies conducted at VTSs, studies of air traffic controllers, discussions with VTS personnel, VTS training manuals, the VTSNY Standard Operating Procedures manual (Commanding Officer, VTSNY, 1993), and the VTSPS Traffic Center Manual (Commanding Officer, VTSPS, 1993). A site visit to VTSNY was made by the investigators on 8 June 1993. The method of direct observation by means of field studies and the use of questionnaires were chosen to most effectively address the measurement of workload (Chapanis, 1959). Two sites were chosen for study, VTS New York and VTS Puget Sound, for reasons discussed below.

Field studies such as employed here have several advantages over laboratory experiments, primarily related to validity. The operator is studied doing the actual task in real time. This method also has its disadvantages, however. The researchers have little control over the variables that affect the task, so that conditions cannot be selected or replicated (Wickens, 1984). Because the study would be conducted on VTS operators in actual performance of their task, the study had to be done on a not-to-interfere basis and with as little inconvenience to the operators as possible. This precluded the use of physiological measures often used in other workload studies such as blood pressure, heart rate, and EEG recordings. Two primary measures of operator workload were therefore chosen, an objective or observable measure and a subjective one. For the objective measure, a form of task analysis was used in which operators were periodically observed while doing their task and their activities were recorded. For the subjective measure, operators were administered a questionnaire when they got off watch, in which they evaluated perceived workload.

2.1 OBJECTIVE MEASURES

For the task analysis, an Activity Log was constructed, a list for manually recording all the separate components of the activities the VTS sector operator might perform in carrying out his or her task. Such items were monitoring or adjusting the controls of the radar sets or the closed circuit television (CCTV), radio communication with vessels, talking with other operators or the Watch Supervisor about the task at hand, and filling out VDCs. Also included were two activities that had no apparent direct bearing on the sector operator's task, the Other category (for example, getting coffee), and the Discretionary Communications category (non-work related talking among watchstanders). The latter two activities were included as potential measures of absence of heavy workload, non-busy free time, or discretionary activities, which could be engaged in when

other task demands were low. Also on the Activity Log were recorded the total number of VDCs handled within that sector, and the maximum number of VDCs at any given time (Peak VDCs), to provide a measure of vessel traffic within each sector.

Additional variables that were expected to affect various aspects of VTS operations including operator workload and performance were recorded on a separate data sheet. The basic forms were modified slightly to customize them for use at each of the two VTS sites studied, reflecting differences in equipment and activities. For example, VTSNY used a magnetic Ferry Board to keep track of ferry traffic. VTSPS used a desktop computer to exchange e-mail, and employed large backlit charts (termed Overhead Plots here) of each sector for showing current fishing zones or for dead reckoning of a vessel's progress, if required.

Audio tapes were recorded of the radio communications for each period that a watchstander was observed, and later analyzed for frequency and duration of communications.

2.2 SUBJECTIVE OPERATOR WORKLOAD (OWL) MEASURES

The selection of the subjective Operator Workload (OWL) measures, operator ratings of personal feelings or judgment of workload conditions, involved a number of criteria for such measures suggested in the literature (Wierwille and Eggemeier, 1993). First, the selected subjective measures must have *sensitivity* to the objective workload. That is, the measure should indicate higher workload for conditions with a greater number of vessels, a greater number of communications, etc. Because the observed level of objective workload proved to be closely tied to "sector," a sensitive measure was one that showed a difference between sectors. Second, the measure should have sufficient *non-intrusiveness* for the operational setting. For the VTS setting that meant that the operators could not be interrupted while "sitting comms," but had to be queried during their next break. Another criterion was the appropriateness of the "*bandwidth*," or the unit of work, that was encompassed by the measure. For the VTS operation, that was one session (approximately one and a half hours) at one sector.

An additional criterion for a workload measure, *diagnosticity*, refers to a measure's ability to diagnose or identify specific aspects of the situation responsible for the subjective workload. For the present study, diagnosticity was the ability to identify specific harbor conditions, task components, or equipment problems that contributed to subjective workload in an observed session. Diagnosticity is of special importance to this study because knowledge of specific contributors to workload would be most effective in guiding changes to task design or to equipment. For this reason, special efforts were made to achieve it. The first attempt borrowed from

an earlier human factors study of VTS operations (Devoe et al., 1979), which had divided operator's activities into "monitoring," "information processing," and "communications." The present study's first data collection at VTS New York asked the operators for separate subjective workload ratings for these three functions. While the ratings for the three functions were successfully sensitive to the objective difficulty of a sector, they were highly correlated with each other. It was apparent that the operators could not separate their feelings about the three functions and were giving substantially the same rating three times. In addition, operators were asked to estimate the percentage of total time that they spent on each of the functions. The time estimates did prove modestly diagnostic in that the reported percentages for each of the three functions were consistently the same over sessions and over sectors. Because of this approach's very limited ability to diagnose the difficult components of the task, it was not repeated at VTS Puget Sound.

For the Puget Sound data collection, the NASA Task Load Index (NASA TLX) (NASA Ames Human Performance Research Group, 1988), a measure widely used in a variety of operational conditions (Hart and Staveland, 1988), was used. This procedure presents the operator with six subscales, asking for ratings of mental demand, physical demand, temporal demand, performance, effort, and frustration. The operator is asked also to weight the relative importance of each subscale to the task and a weighted average of the six subscales is calculated to produce a single score. For simplicity of administration in operational findings, the weighting can be omitted and a simple average used as the single score (Christ et al., 1993; Byers et al., 1989). This simpler procedure was used and it proved successfully sensitive to objective measures. After the NASA TLX, in order to increase diagnosticity, the operator was presented with a Checklist of Potential Contributors to Subjective Operator Workload. The items offered as potential contributors were taken from an internal U.S. Coast Guard memo (U.S. Coast Guard, October 1992), listing characteristics of the Puget Sound sectors. The operator was asked to indicate the degree to which each item had contributed to the just-rated workload. The Checklist results were analyzed separately from the NASA TLX and appear diagnostic in their ability to identify the troublesome components of the sector operator's task.

2.3 REPRESENTATIVE VESSEL TRAFFIC CENTERS

Two Vessel Traffic Centers (VTCs) were designated as sites for the field studies, each being different from the other in several respects.

2.3.1 VTS New York, Governors Island, New York

VTSNY was chosen as a study site because it was the first VTS in the country to be receiving a VTS equipment suite Upgrade. Although the present field study was conducted using the original VTS equipment, the intent was to apply information gathered in this study to the configuration, setup, and use of the VTSNY Upgrade system when it became operational.

The configuration of VTSNY AOR at the time of the study was approximately 110 square miles, using four radar and radio communications sites. This area is shown on NOAA Chart 12327, New York Harbor, and several larger-scale charts. The AOR was divided into three radar sectors as follows (VTSNY, 1993), with high vessel traffic route mileage in nautical miles (NM), later referred to as the variable Sector Miles, as shown:

Mariner's Harbor, Newark Bay, and Kill Van Kull (14 NM);

Upper Bay (21 NM) and the Ambrose Channel sea lane (23 NM)(two radar/communications sites);

Anchorage area, north of the Verrazano Narrows Bridge and the rest of Lower Bay Sector not including Ambrose Channel.

Participation by vessels in the Lower Bay, including Ambrose Channel, was not mandatory, but estimated to be over 90% (VTSNY, 1993). Each sector had its own substantial coverage by CCTV. Radio communications for the entire AOR were conducted over VHF Channel 14 except for the Anchorage Watch, which used Channel 12.

Data were collected only at the Upper Bay and Mariners Harbor Sectors, as these were the principal areas of vessel traffic and whose workload typically far exceeded that at the Anchorage Watch. The VTS was manned in two 12-hour shifts, or watches, per day that changed at 0600 and 1800, with some overlap provided by personnel arriving about one-half hour before their watch officially started. Each watch team normally consists of a Watch Officer, a Watch Supervisor, three sector operators at radar workstations, and a sector operator on stand by. At the time of this study, the sector operators were all enlisted personnel.

The VTSNY AOR can be characterized as having relatively narrow waterways with many nearby shoals, and channels and rivers with sharp bends. The number of participating vessels was approximately 170,000 ships per year, or about 500 per day.

2.3.2 VTS Puget Sound, Seattle, WA

An additional VTS was included for study in order to explore the generality of the findings from VTSNY. VTSPS was chosen because it was scheduled to be second to receive the VTS Upgrade

equipment, and because it is substantially different from VTSNY in several important characteristics.

The AOR of VTSPS covers 25,000 square miles with 12 radar sites and 11 radio communication sites. The area is shown on NOAA Chart 18400, Strait of Georgia and Strait of Juan de Fuca, Chart 18440, Admiralty Inlet and Puget Sound, and numerous larger-scale charts. It is divided into four sectors, as follows, with the number of high vessel traffic route nautical miles (NM) as shown:

Strait of Juan de Fuca Sector, which extends from Puget Sound to the sea, covered by three radar sites (423 NM);
North Sector of Puget Sound, primarily the Rosario Strait and the San Juan Islands area, covered by four radars (508 NM);
South Sector, to Seattle, with three radars, and
Deep South Sector, to Tacoma, with two radars (351 NM combined).

The South Sector operator normally services the Deep South Sector, as well, unless vessel traffic is unusually heavy and another operator is called in to assist.

Each of the sectors has from three to 11 anchorage areas within it, which are monitored by the respective sector operator.

Due to the large geographic area covered, each sector operator must monitor multiple radar screens. Despite the 12 sites, however, not all the AOR is covered by radar. In those areas, the VTS operators have to rely solely on a manual method of tracking vessels based on frequent radio communications, termed the Vessel Movement Reporting System (VMRS). CCTV coverage is minimal, covering only a small but often busy portion of the middle of the South Sector. For radio communications, the Strait and North Sectors share VHF Channel 5A, and the South and Deep South Sectors use Channel 14. In the Strait and North Sectors, frequent communication occurs with the Canadian VTS, exchanging cognizance of vessels that cross the international border.

VTSPS is manned in three eight-hour watches per day, each watch normally consisting of a watch supervisor, three sector operators at radar workstations, another sector operator for administrative duties, additional communications, and to assist the South Sector operator when required, and a fifth sector operator to stand by. Watchstanders were both U.S. Coast Guard and civilian personnel.

Much of the Puget Sound area waters are navigable, with an average depth of 600 feet. However, a Traffic Separation Scheme, marked by buoys, establishes traffic lanes for large shipping. These traffic lanes are regularly crossed by ferries and

frequently transited by fishing fleets, yacht regattas, and submarines, which often run submerged without radio communications. The Strait of Juan de Fuca can have waves up to 20 feet high, and the entire area is subject to frequent visibility problems due to fog.

The number of participating vessels at VTSPS was more than 200,000 ships per year, or over 700 per day.

2.3.3 The VTS Sector Operator's Task

In order to study workload effectively in the VTS setting, complete familiarity with the operator's task was required, of course. This was gained from the sources mentioned above and from observation of a number of watchstanders before the study was begun. What follows is a brief description of some of the sector operators' more important duties to familiarize the reader with the various aspects of the task.

Before the start of each day, the VTS generally gets a partial list of vessels expected in its Area of Responsibility (AOR). When a vessel that is required to participate in VTS enters the AOR, it calls in via radiotelephone to the VTC, identifies itself, and states its destination. These radio communications are typically conducted over VHF Channels 14 or 5A. The VTS operator for the geographic sector that the vessel is entering observes the vessel on radar, where possible, acknowledges the report from the vessel, fills out a Vessel Data Card containing information about the ship, and time stamps the card. The VDC is then placed near the radar screen. As the vessel moves through the sector, the operator moves the VDC around the screens correspondingly.

When passing various points in a sector, the vessel may be required to report its progress to the VTS operator, necessitating an exchange in radio transmissions and usually an additional time stamp on the VDC. This process continues until the vessel leaves that radar sector, at which time the vessel's progress and the VDC are passed off to the operator of an adjacent sector, or the vessel reaches its destination.

Similarly, when a participating vessel leaves its slip or anchorage, it contacts the VTS and a record is kept of its progress through the sector, whether the vessel is headed out to sea or, as in the case of ferries and tugboats pulling barges, travels around in one or more sectors of the AOR.

The VTS operator carries out this task for each vessel in his or her sector, transmitting advisories to individual vessels about approaching vessel traffic, hazardous conditions, and other pertinent information, and answering inquiries from vessels. At

some times the operator must keep track of dozens of vessels simultaneously.

Other activities required of the VTS operator are to adjust radiotelephone and radar controls and, where available, CCTV controls, communicate with the Watch Supervisor and other watchstanders, and listen for weather bulletins and emergency radio broadcasts. Operators also monitor radio communications among ships on two additional channels. The watch on each sector usually lasts one or two hours, after which time the operator switches to another of the three sectors or goes on a break, standing by as relief. VTS is operated on a continuous basis, with rotating shifts of watchstanders.

3.0 INVESTIGATION AT VTS NEW YORK

3.1 TASK COMPONENTS AND SECTOR DIFFERENCES

3.1.1 Method

At the start of the site visit, the investigators met with VTS senior personnel and with watch section personnel to discuss the purpose and nature of the study. Before any data collection, the individual operators read and signed an Informed Consent package, which gave details of the methodology to be used and statements of voluntary and anonymous participation.

Data were collected from both the Mariners Harbor and Upper Bay Sectors simultaneously during 11 thirty-minute observation periods over three days in July 1993, for a total of 22 observation periods. Individual investigators collected data from each sector. The times of data collection were generally chosen to sample periods of high vessel traffic.

Immediately before the start of each half-hour observation period, the investigator filled out the data sheets with as much information as was available. Activity Log data were then collected, with the investigator putting a tick mark beside each activity in which an operator was engaged, every 15 seconds throughout the half hour. Sometimes the operator would be engaged in more than one activity, for example looking at VDCs and talking on the radio. In those cases, the investigator would place a tick mark under both activities for that time. During later analysis, the tick marks were added up to give a sample of the relative frequency of each activity performed in the sector operator's task. During the observation period, the investigator also kept a count of the total number of VDCs and the maximum number of VDCs at one time in that sector. A tape recording of radio Channel 14 was made for each observation period.

When the sector operator subsequently was off sector watch, the subjective workload and background questionnaires were administered in a room next to the VTS center. The operator was informed of the sector and time for which he or she was to evaluate the workload and filled out the forms accordingly.

After the site visit, the radio communication tapes were analyzed to obtain the following information for each observation period: number of Operator Radio Transmissions to vessels, number of Vessel Radio Transmissions to the VTS operator, and total communication time in seconds for that half hour.

Watch personnel from each VTS site provided estimates of high vessel traffic density route mileage within each sector, referred to as Sector Miles, for use in subsequent analyses.

3.1.2 Results and Discussion

Data for each observation period were entered into a computer spreadsheet program and mean values were calculated for each sector. Two variables derived from other measures were also calculated, Mean Total Number of VDCs per Sector Mile, and Mean Peak Number of VDCs per Sector Mile. Mileage for Ambrose Channel was not included in this analysis. These data are summarized in Table 3-1 for each sector and for both sectors combined. The table is divided into six groups of measures, depending on the type of variable and the source of the data. For some variables, *t* tests were computed between the measures for the two sectors, also shown in the table.

Most apparent is the fact that the Upper Bay Sector is considerably busier than the Mariners Harbor Sector, as indicated by the significantly greater mean number of VDCs and therefore number of vessels. This difference is reflected in the generally greater frequency in Real-Time Activities for Upper Bay, although the monitoring of Radar was the only one statistically significant. (There was no Ferry Board at the Mariners Harbor Sector station.) In contrast, the less busy Mariners Harbor Sector had a much higher frequency of Discretionary Activities. This would additionally indicate that the Upper Bay Sector operator has a higher workload than the Mariners Harbor Sector operator.

Further, the Radio Communications data also support this conclusion. The Upper Bay Sector operator engaged in almost twice the number of interchanges with vessels and spent twice as much time on Radio Comms as the Mariners Harbor Sector operator.

The number of VDCs per Sector Mile (traffic density) was virtually the same for both sectors. Although the Upper Bay Sector handled more vessels, its sector route mileage, even with the exclusion of the Ambrose Channel mileage, was proportionally greater. This indicates that, at least for the New York AOR, it is not necessarily the vessel traffic *density* that contributes to operator workload, but rather just the actual number of vessels.

For both sectors combined, the counts of operator activities were converted to percentages and are given in the last column of the table. It can be seen that almost one-fourth of the operator's activity is spent monitoring Radar. Working with VDCs (filling them out and further time-stamping, annotating, and moving them) makes up nearly another one-fifth of activities. CCTV and communicating with vessels make up the bulk of the rest of the operator's task.

Table 3-1 VTS New York Measures

SECTOR	MARINERS HARBOR			UPPER BAY						COMBINED	
Sector Miles	14			21							
MEASURES	**Mean**	StdDev	n	**Mean**	StdDev	n	*t*	*df*	*p*	**Mean**	**% of Total**
HARBOR FACTORS (Mean value per half-hour observation)											
Total # VDCs	**7.7**	3	11	**12**	3.7	11	-3.0	19	<.01	**9.9**	
Peak # VDCs	**6.3**	2.1	11	**9.7**	3.6	11	-2.8	16	<.05	**8.0**	
Total # VDCs/Sector Mile	**0.6**	0.2	11	**0.6**	0.2	11	-0.2	19	ns	**0.6**	
Peak # VDCs/Sector Mile	**0.4**	0.2	11	**0.5**	0.2	11	-0.2	19	ns	**0.5**	
REAL-TIME ACTIVITIES (Activity Log: Mean frequency per half-hour observation)											
Radar	**22.8**	13.8	11	**36.1**	12.1	11	-2.4	19	<.05	**29.5**	**23.5**
CCTV	**18.2**	10.6	11	**16.7**	10.4	11	0.3	19	ns	**17.5**	**13.9**
Vessel Comms	**15.2**	6.4	11	**20.2**	8	11	-1.6	18	ns	**17.7**	**14.1**
Working with VDCs	**21.9**	12.2	11	**26.5**	7.3	11	-1.1	16	ns	**24.2**	**19.3**
Looking at VDCs	**6**	6.3	11	**3.8**	3.1	11	1.0	14	ns	**4.9**	**3.9**
Adjusting Comm Controls	**2.1**	2.2	11	**1.5**	2.6	11	0.5	19	ns	**1.8**	**1.4**
Ferry Board	0	-	-	**0.8**	0.9	11				**0.4**	**0.3**
Prof Comms	**13.2**	10.6	11	**7.1**	2.5	11	1.9	11	as	**10.1**	**8.0**
DISCRETIONARY ACTIVITIES (Activity Log: Mean frequency per half-hour observation)											
Extraneous Communications	**12.7**	14.4	11	**3.6**	4.2	11	2.0	11	as	**8.2**	**6.5**
Other Extraneous Activities	**15.7**	14.6	11	**6.9**	6.6	11	1.8	13	as	**11.3**	**9.0**
RADIO COMMUNICATIONS (Tape Recordings: Mean value per half-hour observation)											
Oper. Radio Transmissions	**21.8**	12.2	10	**42.9**	20.5	10	-2.8	14	<.05	**32.4**	
Vessel Radio Transmissions	**27.2***	8.6	10	**53.5***	16.8	10	-4.4	13	<.01	**40.3**	
Comms Time (total seconds)	**154***	60.6	10	**303***	119.3	10	-3.5	13	<.01	**228.5**	
Comms Time (percent)	**8.6**			**16.8**						**12.7**	
SUBJECTIVE MEASURE (Questionnaire: Mean rating for observations)											
Subjective Workload	**33**	17.0	15	**47**	18.8	12	-2.1	22	as	**40**	
as (approaches significance): .05 < p < .10											
ns (non-significant): p => .10							**Activity Total**			**125.6**	**100**
* Estimate based on Operator Radio Transmissions ratio between Sectors											

3.2 SECTOR OPERATORS' SUBJECTIVE REPORTS

3.2.1 Method for Subjective Measures and Questionnaire

After each session for which Activity Log data were taken, during the operator's next rotation to a break period, he or she was de-briefed by a researcher. The most important part of the de-briefing was an Operator Workload rating scale, designed for the situation. The scale presented definitions of three major functions, definitions that had been generated with assistance from several Watch Supervisors and experienced operators. "Monitoring" was defined as monitoring of radio Channel 14, of Channel 13, of traffic on radar, of traffic on the CCTV, and examining the VDCs. "Information processing" was defined as writing on VDCs, moving VDCs (around the radar screens to track the relevant ships), moving CCTV cameras, talking to other operators, formulating advisories (to communicate to ships) and preparing operational notes (opnotes, also to communicate to ships). "Communications" was defined as calling ships, using Channel 13 to instruct ships to change to Channel 14, responding to ships, and passing advisories and opnotes. The operator was first asked to rate the subjective workload of each of these three functions, and then was asked to estimate the percentage of total time that had been spent on each.

3.2.2 Results of Subjective Measures

Preliminary analyses of the debriefing results were done to examine the effectiveness of the subjective measures in discriminating between the two Sectors and among the three functions of Monitoring, Information Processing, and Communications. Ratings of subjective workload were sensitive to the Sectors: approximately 33 (out of 100) for Mariners Harbor and 45 for Upper Bay. The operator's estimates of the percentage of time spent were sensitive to the three functions: approximately 37% for Monitoring, 36% for Information Processing, and 27% for Communications. These data were combined into one measure: the mean of the workload ratings, each weighted by the percentage of time for which it would have been operative, multiplied by 100. The resulting calculated values of 33 for Mariners Harbor and 47 for Upper Bay appear in Table 3-1, and in subsequent analyses as Subjective Workload. This final measure was sensitive to the more frequent activities and communications in Upper Bay, as can be seen in the table.

3.3 ANALYSIS OF SECTOR OPERATOR PERFORMANCE

3.3.1 Summary Correlation Matrix

The Pearson product-moment correlation coefficients (r) were computed between selected measures for which there were sufficient data. A selection of these results is presented as a

half-matrix in Table 3-2. Some measures were not included here because they appeared redundant or unrevealing. Sector was the determining factor for Number of VDCs (and therefore number of participating vessels). Sector was therefore significantly correlated with frequency of Radar monitoring and radio communications activities, both frequency of Vessel Communications (from the Activity Log data) and Radio Communications (from the recorded tapes).

Number of vessels (#VDCs) was significantly correlated with the mean frequencies of major Real-Time Activities of Radar monitoring, Vessel Communications, and Working with VDCs, and with the measures of Radio Communications taken from the recorded tapes. It was also correlated with Subjective Workload, and negatively correlated with Discretionary Communications. Vessels per Sector Mile showed a similar pattern of correlations with the other measures. Real-Time Activities were generally positively correlated with Radio Communications and negatively correlated with Discretionary Communications.

Discretionary Communications also showed significant negative correlations with measures of Radio Communications and Subjective Workload. Radio Comms produced significant correlations among themselves and with Subjective Workload. Measures of Distribution of Time and Subjective Workload also had significant correlations among themselves. The significance of these statistical relationships is discussed below.

3.3.2 Criticality of Measures to the Sector Operator's Task

Based on all the foregoing results, certain of the most meaningful measures were selected for two additional types of analyses as means for providing additional understanding of the operator's task and the contributions to operator workload. These two methods are nonmetric multidimensional scaling, discussed here, and path analysis, discussed in Section 5. They are complementary methods for describing the complex relationships given in the Summary Correlation Matrix.

Nonmetric multidimensional scaling (Kruskal, 1964a, 1964b; Shepard, 1962a, 1962b) is a mathematical technique used for determining the underlying organization of a set of related items of data, each of which having some measure of similarity to every other item in the set. This methodology has been successfully used in such varied contexts as decision making in antisubmarine warfare (Zachary, 1980), and prioritization and retrieval of sonar information (Laxar, Moeller, & Rogers, 1983, 1989), as well as color perception, auditory perception, market research, and cognitive maps of one's environment. In the present case, the items were 19 selected measures from the operator's task, and the

Table 3-2

Selected Correlations from VTS New York

	Sector	#VDCs	Radar	Vessel Comms	Working with VDCs	Discret. Comms	Vessel Radio Trans
#VDCs	.59**						
Radar	.58*	.54*					
Vessel Comms	.34	.63**	.08				
Working with VDCs	.40	.60**	.24	.37			
Discret. Comms	-.46	-.75***	-.57*	-.50*	-.77***		
Vessel Radio Trans	.74***	.84***	.54*	.58*	.46	-.57*	
Subjective Workload	.44	.56*	.11	.44	.70**	-.54*	.65**

* $p < .05$; ** $p < .01$; *** $p < .001$

metric of similarity between all 171 possible pairs of measures were the correlation coefficients.

The similarities half-matrix was the input to the KYST-2A multidimensional scaling program (Kruskal, Young, & Seery, 1977). Through this computerized technique as employed here, a configuration of points, each representing an individual measure, is constructed in Euclidean space by an iterative adjustment process, based on the measured similarities between all pairs of stimuli. The final configuration is then rotated so that the principal components of the points lie along a coordinate axis. The computer analysis was repeated with several random starting configurations to ensure that the final solution reached was optimal.

In accordance with the guidelines given by Shepard (1974), based on the data values in the similarities matrix, the configuration of the plots, and the meaningfulness in the interpretation of the axes, the final solution was one-dimensional, that is, the measures fell on a straight line and could be ordered along a single axis of arbitrary units. The resulting solution is presented in Figure 3-1.

The labeling of the axes in a multidimensional scaling configuration is, for the most part, based on the information available to the investigators about the set of items being scaled. Based on this information, examination of Figure 3-1 suggests that the dimension along which the measures fall is Criticality to the sector operator's task. Monitoring of Radar and Information Processing Percent of Time fell at the high end of the scale, followed closely by Sector, Number of VDCs, and some activities considered by many VTS personnel to be critical to the operator's task, especially radio communications. In the middle of the scale are some activities that are sometimes engaged in, but are less critical. Finally, at the low end of the scale are the Discretionary Activities. It can be noted that positively correlated variables group together and negatively correlated variables fall at opposite ends of the dimension. In accordance with the scaling algorithm, activities that are closely related tend to group together, whereas activities not closely related or negatively related are located proportionally apart.

Results of this analysis may be taken as an indication of the sources and tasks of the sector operator's workload, and are a mathematically derived ordering of the measures taken in the VTS center. They elucidate the results shown in Table 3-2, and suggest that the Sector and the number of vessels (VDCs) are critical to the source of operator workload. Associated with those measures are the activities that place a time demand on the operator, the subjective evaluations of a large time spent processing information, and Subjective Workload. Other

MOST CRITICAL ↑

- **Radar Monitoring**
- Information Processing Percent of Time (questionnaire)

- Sector
- **Vessel Radio Transmissions** (recordings)
- **# VDCs**
- Comms Time (total seconds) (recordings)
- Operator Radio Transmissions (recordings)
- Subjective Workload
- # Vessels per Sector Mile
- **Working with VDCs**
- **Vessel Comms**

- Comms Time (percent) (recordings)
- Looking at VDCs

- Monitoring CCTV

- Comm Controls

- Professional Communications

- Monitoring Percent of Time (questionnaire)

- Discretionary -- Other
- **Discretionary -- Communication**

↓ LEAST CRITICAL

Figure 3-1. Unidimensional scaling results for VTS New York variables. Bolded items are those of particular importance in other analyses.

activities, farther down the scale, are those that can be done on a time available basis, with decreasing importance to the operator's task.

3.4 SUMMARY AND CONCLUSIONS FOR VTSNY

The geographical Area of Responsibility for VTSNY is relatively small. The number of participating vessels within this area, however, makes traffic density substantial, especially in view of the narrow waterways involved. It is clear that the Upper Bay sector operator had a greater workload than the Mariners Harbor operator. The two sectors had almost identical traffic density, as measured in number of Vessels per Sector Mile (excluding the Ambrose Channel mileage), but the Upper Bay sector had significantly more participating vessels, which produced a higher frequency of Real-time Activities, allowing for fewer Discretionary Activities. The Subjective Workload rating was higher for the Upper Bay Sector than Mariners Harbor.

The Activity Log results show that most of the sector operator's workload consists of monitoring Radar, Working with VDCs, and conducting radio communications. These activities were shown by the multidimensional scaling analysis to be the most critical to the operator's task. Further discussion of these results and their implications are presented in Section 5.

4.0 INVESTIGATION AT VTS PUGET SOUND

4.1 TASK COMPONENTS AND SECTOR DIFFERENCES

4.1.1 Method

Data were collected during 17 thirty-minute observation periods over three days. During a given period, data were simultaneously taken on the South Sector, reported as the busiest, and one or both of the other two sectors, for a total of 11 from the Strait of Juan de Fuca Sector (Strait), 11 from the San Juan Island Sector (North), and 17 from the Puget Sound Sector (South), or a combined total of 39 observation periods. The times of data collection were generally chosen to sample periods of high vessel traffic.

Data were collected in a similar manner to that done at VTSNY, using data sheets designed for the specific conditions of VTSPS. Some audio tapes of radio communications, however, contained no data or were of poor quality. In addition, the Strait and North Sectors shared the same channel (5A), and the data could not be directly separated by sector. The Radio Communications data from the Strait and North Sectors were therefore divided proportionally by an estimate based on the ratio of Number of VDCs between the two sectors, since there were high significant correlations between Number of VDCs and the three Radio Communications measures. Radio Communications data consisted of 12 observation periods for the Strait and North Sectors combined and 15 observation periods for the South Sector, for a total of 27 out of the 39 periods for which complete data were collected.

4.1.2 Results and Discussion

The data from VTS Puget Sound were analyzed in a similar manner to that from VTS New York. They are summarized in Table 4-1. For some variables, one-way analyses of variance (ANOVAs) were computed between the measures for the three sectors, also shown in the table. Not all sector stations had the capability to perform all activities: there were no vessels at Anchor Watch in the South Sector, only the South Sector had CCTV, and Strait and North Sectors shared duties on a PC to get e-mail.

Most evident in Table 4-1 is the fact that the South Sector handles much more traffic than either of the other two sectors. Although the South Sector has the fewest Sector Miles, it has more than twice the Number of VDCs of either the Strait or North Sectors. The VDCs per Sector Mile, that is, the vessel density, for the South Sector is thus approximately three times that of the Strait or North Sectors.

Table 4-1 VTS Puget Sound Measures

SECTOR	STRAIT			NORTH			SOUTH						COMBINED	
Sector Miles	423			508			351							
MEASURES	Mean	StdDev	n	Mean	StdDev	n	Mean	StdDev	n	*F*	*df*	*p*	Mean	% of Total
HARBOR FACTORS (Mean value per half-hour observation)														
Total No. VDCs	14.5	2.6	11	14.4	4.7	11	33.1	3.8	17	116.40	2, 36	<.001	22.6	
VDCs/Sector Mile	0.03	0.01	11	0.03	0.01	11	0.1	0.01	17	222.52	2, 36	<.001	0.1	
# Vessels in Anchor Watch	0.6	0.7	11	0.6	0.7	11	0.0	0.0	17	5.43	2, 36	<.01	0.3	
REAL-TIME ACTIVITIES (Activity Log: Mean frequency per half-hour observation)														
Radar: Monitoring	36.7	15.2	11	25.8	7.9	11	30.2	10.2	17	2.62	2, 36	as	30.8	
Radar: Adjusting Controls	3.6	2.4	11	2.8	2.6	11	5.3	5.1	17	1.48	2, 36	ns	4.1	
Radar: Total	40.4	15.7	11	28.6	9.3	11	35.5	11.4	17	2.56	2, 36	as	34.9	25.3
CCTV Monitoring	0.0	-	-	0.0	-	-	2.8	3.7	17				1.2	0.9
CCTV Adjusting Controls	0.0	-	-	0.0	-	-	4.0	5.6	17				1.7	1.3
Vessel Comms	17.1	13.6	11	18.8	9.7	11	37.3	13.8	17	11.17	2, 36	<.001	26.4	19.1
Prof Comms with Watch Supervisor	3.3	3.0	11	4.1	3.8	11	4.3	6.1	17	0.16	2, 36	ns	4.0	2.9
Prof Comms Between Operators	8.2	5.4	11	17.2	10.2	11	10.5	10.7	17	2.81	2, 36	as	11.7	8.5
Working with VDCs	15.5	5.3	11	19.1	6.6	11	26.8	9.1	17	8.38	2, 36	<.01	21.4	15.5
Looking at VDCs	7.3	4.7	11	8.0	6.0	11	13.9	6.9	17	5.07	2, 36	<.05	10.4	7.5
Adjusting Comm Controls	2.1	2.0	11	1.5	1.4	11	0.7	1.6	17	2.34	2, 36	ns	1.3	0.9
Using Telephone	2.8	2.0	11	2.7	3.1	11	0.1	0.2	17	9.44	2, 36	<.001	1.6	1.2
Overhead Dead Reckoning Plot Monitoring	3.4	2.6	11	6.1	5.7	11	2.5	2.5	17	3.29	2, 36	<.05	3.7	2.7
Overhead Dead Reckoning Plot Entering	1.9	2.3	11	3.0	2.1	11	0.3	0.7	17	8.84	2, 36	<.001	1.5	1.1
PC (E-Mail)	7.7	7.7	11	1.7	3.9	11	0.0	-	-	t=2.31	14	<.005	2.7	1.9
Other Official Activities (Forms, etc)	6.4	3.4	11	5.4	5.9	11	3.1	3.0	17	2.32	2, 36	ns	4.7	3.4
DISCRETIONARY ACTIVITIES (Activity Log: Mean frequency per half-hour observation)														
Extraneous Communications	4.0	4.5	11	8.8	9.9	11	2.3	3.5	17	3.81	2, 36	<.05	4.6	3.3
Other Extraneous Activities	6.6	5.4	11	10.7	6.1	11	2.8	3.5	17	8.72	2, 36	<.001	6.1	4.4
RADIO COMMUNICATIONS (Tape Recordings: Mean value per half-hour observation)														
Oper. Radio Transmissions	26.0	11.0	7	26.0	11.0	9	63.0	21.0	15	18.77	2, 28	<.001	44.1	
Vessel Radio Transmissions	26.0	11.0	7	28.0	11.0	9	72.0	22.0	15	25.43	2, 28	<.001	48.8	
Comms Time (total seconds)	169.0	73.0	7	199.0	92.0	9	499.0	241.0	15	11.71	2, 28	<.001	337.2	
Comms Time (percent)	9.4	4.1	7	11.1	5.1	9	27.7	13.4	15	11.71	2, 28	<.001	18.7	
SUBJECTIVE MEASURES (Questionnaire: Mean rating for observations)														
NASA Average	27.5	26.2	6	39.8	20.2	6	50.5	13.8	11	2.81	2, 20	as	41.7	
Mental Demand	39.2	32.2	6	48.3	18.9	6	70.0	15.0	11	4.58	2, 20	<.05	56.3	
Time Demand	37.5	33.0	6	44.2	19.1	6	64.6	17.9	11	3.21	2, 20	as	52.2	
as (approaches significance): .05 < p < .1										Activity Total			137.9	100.0
ns (non-significant): p=>.10														

The higher workload of the South Sector is evidenced by the much greater frequency of Vessel Communications, and Working with and Looking at VDCs. Time for Discretionary Activities was at a minimum for the South Sector operator, as shown by the substantially lower frequency of the Discretionary Communications and Other activities compared to the other two sectors.

The Radio Communications data parallels the Vessel Communications frequency counts, with the South Sector radio transmissions and time being greater than the other two sectors combined.

The relative percentages of Real-Time Activities were calculated for the three sectors combined. Because South Sector had a greater number of measures than North or Strait, its values are more heavily weighted in the resulting percentages. The Real-Time Activities engaged in at VTS Puget Sound were similar to those of VTS New York, with Radar making up the greatest, 25.3%. Vessel Comms and Working with VDCs were also high. While CCTV activity was substantial (13.9%) at VTSNY, it was not an issue at VTSPS, since only one sector had it available. VTSPS engaged in other activities not available at VTSNY, however, such as Telephone usage, Overhead Plots, and PC (E-mail), which together comprised almost as much activity. On average, Discretionary Activities in the sectors at VTSPS were about half that of VTSNY.

4.2 SECTOR OPERATORS' SUBJECTIVE REPORTS

4.2.1 Method for Subjective Measures and Questionnaire

The principal parts of the debriefing at VTSPS were the NASA Task Load Index (NASA TLX) and a Checklist asking the operator to indicate which factors had contributed to the experienced workload. The NASA TLX consists of six subscales, each presented along with a definition of what is intended: mental demand, physical demand, temporal demand, performance, effort, and frustration. For each subscale, the operator was asked to indicate a rating for the session just completed from low (0) to high (100). This procedure was followed by a Checklist of Potential Contributors To Subjective Workload. The Checklist offered contributors including activities (for example, monitor radar), responsibilities (for example, watch anchorage areas), and user types (for example, ferries crossing Traffic Scheme). The operator was asked to rate each item in the Checklist as to whether it:

0 - made no contribution to session
1 - made minimal contribution
2 - made significant contribution
3 - made major contribution
4 - interfered with other tasks
5 - required an additional operator

The questionnaire concluded with space to report any unusual or stressful incidents during the session and a request for biographical data.

4.2.2 Results of Subjective Measures

Data from the principal subjective measure collected at VTSPS, the NASA TLX, were analyzed. The overall score and two of the subscales, Mental Demand and Time Demand, are included in Table 4-2. There they appear sensitive to the differences in the frequency of activities and communications among the sectors, reflecting especially the high frequencies in the South Sector.

Table 4-2

Subjective Ratings on NASA Task Load Index

SUMMARY	STRAIT	NORTH	SOUTH
Mental Demand	39	43	69
Physical Demand	18	36	43
Time Demand	38	39	66
Own Performance	3	4	27
Overall Effort	39	45	60
Frustration	28	35	36
MEAN	27	34	50

The Checklist of Potential Contributors to Subjective Workload was analyzed to identify specific contributors to the subjective workload reported on the NASA TLX. The results are presented in Table 4-3. The first column is a one- or two-word description of the potential contributor. The values presented are the means and standard deviations over operator ratings of 39 sessions, ratings from zero (did not contribute to session) to four (interfered with other tasks). There are no means as high as four. Five (required an additional operator) was never selected during the sessions observed. No statistical tests were done on these data.

The first block of items corresponds approximately to the activities in Table 4-1. As was the case for the Activity Log data, the Checklist data identified radar monitoring, communications with vessels, and working with VDCs as the major activities. However, the relative reported contributions of these activities over the three sectors did not correspond to their relative observed frequencies for the sectors. As summarized in Table 4-1, radar monitoring was *more* frequently observed in the Strait Sector than it was in the other sectors. However, as shown in Table 4-3, radar in the Strait Sector was

Table 4-3

Summary of Reported Contributors to Subjective Workload

CONTRIBUTOR	STRAIT mean	STRAIT sd	NORTH mean	NORTH sd	SOUTH mean	SOUTH sd
adjust radar	**1.50**	0.93	**2.00**	1.00	**2.17**	0.94
monitor radar	**2.75**	0.46	**3.14**	0.38	**3.08**	0.29
OH, VMRS	**1.00**	1.60	**2.14**	1.07	**1.58**	1.00
data RDDS	na	na	na	na	**1.67**	0.89
monitor RDDS	na	na	na	na	**1.75**	0.75
adjust comms	**1.13**	0.99	**2.86**	0.69	**2.25**	1.29
monitor comms	**2.25**	1.16	**3.00**	0.58	**2.67**	0.78
plan advisories	**1.75**	0.89	**2.57**	0.53	**2.50**	0.80
comm vessels	**2.38**	1.19	**3.14**	0.38	**3.00**	0.60
adjust CCTV	na	na	na	na	**1.27**	1.01
monitor CCTV	na	na	na	na	**1.45**	1.13
write VDC	**2.13**	1.13	**2.29**	0.76	**2.50**	0.80
review VDC	**1.88**	0.99	**2.29**	1.11	**2.17**	0.94
VDC File	**0.63**	0.52	**1.00**	1.00	**1.00**	0.63
anchorage	**0.50**	0.53	**0.57**	0.53	**0.17**	0.39
non-partcpnts	**0.50**	0.76	**1.43**	0.98	**1.67**	1.30
Un Incid, Viol	**0.75**	1.39	**0.57**	1.51	**0.83**	1.03
Canadian	**2.00**	0.93	**1.71**	1.11	na	na
language	**2.25**	1.67	**0.57**	1.51	na	na
area of port	**1.50**	1.60	**2.29**	1.25	**2.58**	1.08
without pilots	**1.75**	1.28	**1.57**	1.62	**1.67**	1.30
military	**1.88**	1.64	**1.71**	1.89	**0.75**	1.14
weather, visib	**1.25**	1.16	**0.86**	1.46	**0.33**	0.65
rain, radar	**0.38**	0.74	**1.14**	1.68	**0.17**	0.39
fishing/TSS	**1.25**	1.04	**1.43**	1.81	**1.92**	1.38
environment	**0.25**	0.46	**1.71**	1.25	**0.25**	0.45
recreational	**0.13**	0.35	**1.00**	1.15	**2.17**	1.34
tide/tugs	**0.13**	0.35	**1.71**	1.25	**1.17**	1.03
commercial	**0.63**	1.06	**1.57**	1.27	**1.25**	0.97
ferries/TSS	**0.00**	0.00	**2.43**	0.53	**3.08**	0.51
sea trials	**0.13**	0.35	**0.86**	1.21	**0.50**	0.80
non req tugs	**0.25**	0.46	**1.14**	1.35	**1.08**	0.90
wake adv	**0.25**	0.71	**1.14**	1.46	**0.83**	1.03
SAR	**0.38**	1.06	**1.14**	1.95	**0.17**	0.58
tour boats	**0.13**	0.35	**1.71**	1.38	**1.08**	1.00
evnts/regtts	**0.13**	0.35	**1.14**	1.46	**1.25**	1.76
	n=8		n=7		n=12	

less frequently reported to be a major contributor to workload than it was in the other sectors. One interpretation of this apparent inconsistency is that the observed high frequency of monitoring in the Straits was the result of the lower frequency of other activities. Operators monitored the radar when no other activity demanded their attention and that discretionary monitoring was not perceived by them as demanding.

As shown in Table 4-1, the South Sector was conspicuous for the greater observed frequency of communications on several measures. However, in Table 4-3 the South Sector did not show reported ratings of workload for communications as high as those for the North Sector. While the communications of the South Sector were more frequent, apparently they were not perceived as more demanding. One reason might have been that the South Sector has a dedicated primary radio channel, 14, while the North and Strait Sectors share Channel 5A, competing for access. Similarly, the South Sector's conspicuously higher number of VDCs and greater frequency of handling them was not reflected in conspicuously higher operator reports of their contribution to workload. More frequent was not necessarily more demanding.

The rest of Table 4-3 suggests other sector responsibilities as potential contributors to workload. Contributors with a mean score of two (made significant contribution) or higher in the Strait Sector were the Canadian hand-off and English language deficiencies on the vessel with which the operator is communicating. Major contributors identified in both the North Sector and the South Sector were the areas of ports and ferries crossing the Traffic Separation Schemes. While congestion in particular locations was often mentioned by operators as a source of workload, this Checklist is one of the few places that showed evidence of this effect. (Note that these reported contributors apply only to the sessions that were observed during several days in October 1993. Other factors may have been bigger contributors at other times and during other seasons.)

4.3 ANALYSIS OF SECTOR OPERATOR PERFORMANCE

4.3.1 Summary Correlation Matrix

Correlation coefficients between pairs of measures were computed in like fashion to the VTSNY measures and are presented as a half matrix in Table 4-4. Most results were similar to those obtained at VTSNY. Sector was the determining factor for Number of VDCs, a measure of number of vessels handled during the periods of observation. Sector was also significantly correlated with frequencies of Vessel Communications, Working with VDCs, and the measures of radio communications. Unlike VTSNY, however, frequency of monitoring radar was not correlated with Sector.

Table 4-4

Selected Correlations from VTS Puget Sound

	Sector	#VDCs	Radar: Monitor	Vessel Comms	Working with VDCs	Discret. Other	Vessel Radio Trans
#VDCs	.83***						
Radar: Monitor	-.20	-.01					
Vessel Comms	.57***	.54**	-.20				
Working with VDCs	.55***	.56***	-.14	.76***			
Discret. Other	-.32*	-.38*	-.42**	-.61***	-.46**		
Vessel Radio Trans	.73***	.71***	-.25	.78***	.78***	-.45*	
Subjective Workload	.55**	.60**	-.32	.66***	.37	-.29	.53*

* $p < .05$; ** $p < .01$; *** $p < .001$

Number of vessels was significantly correlated with frequencies of Vessel Communications and Working with VDCs, and with measures of radio communications, but again, not with Radar Monitoring. More vessels in a sector naturally prompted a greater number of communications with vessels and more handling of VDCs. Number of vessels was also correlated with Mental Demand, shown in Table 4-4 as Subjective Workload, and was negatively correlated with Discretionary Activities. Vessels per Sector Mile showed the same pattern of correlations as did number of vessels. Working with VDCs was highly correlated with frequency of Vessel Communications. Radio communications measures, in general, were also significantly correlated with the Subjective Workload.

In general, Discretionary Activities were significantly negatively correlated with Real Time Activities, and Radio Communications. The more time the operator spent on radio comms and other activities, the less time was available for activities unrelated to the VTS task.

4.3.2 Criticality of Measures to the Sector Operator's Task

A nonmetric multidimensional scaling analysis was conducted on 26 measures of the VTS Puget Sound data in the same manner as was done on the VTS New York data. Here too, the analysis showed that the variables were ordered along a linear axis, with criticality to the operator's task as the relevant dimension. The resulting solution is presented in Figure 4-1.

Once again, positively correlated variables group together in the area of high criticality and negatively correlated variables fall at the opposite end of the dimension, in accordance with the scaling algorithm. Radio communications, and the associated VDC measures comprise the highest criticality. Associated with these are the subjective measures of Mental and Time Demand and the NASA Task Load Index. Discretionary activities, Telephone, and Sector Miles comprise the least critical extreme of the dimension. Activities such as Looking at VDCs, Comm Controls, and Professional Communications fall in the middle of the criticality dimension. These results are similar to those obtained at VTS New York. Unlike New York, however, Radar Monitoring was not the most critical activity, but rather fell in the middle of the dimension. This reflects the lack of significant correlations between this measure and other variables.

4.4 SUMMARY AND CONCLUSIONS FOR VTS PUGET SOUND

The AOR and Sector Miles of VTSPS is many times larger than that of VTSNY. The number of participating vessels at VTSPS is larger but the traffic density in Vessels per Sector Mile is much lower than at VTSNY. The proportion of the various activities of

MOST CRITICAL
↑

- # Vessels per Sector Mile
- **Vessel Radio Transmissions** (recordings)
- **# VDCs**
- Comms Time (percent) (recordings)

- **Vessel Comms**
- **Working with VDCs**
- Sector
- Mental Demand

- Time Demand
- Looking at VDCs
- NASA Average

- Watch Supervisor Comms

- Adjust Radar

- Professional Comms
- Total Radar (Monitor and Adjust)
- **Monitor Radar**

- Comm Controls
- Overhead Plot -- Monitor

- Overhead Plot -- Enter info

- Other -- Official

- PC (E-mail)
- **Discretionary -- Communication**

- Discretionary -- Other

- Telephone
- Sector Miles

↓
LEAST CRITICAL

Figure 4-1. Unidimensional scaling results for VTS Puget Sound variables. Bolded items are those of particular importance in other analyses.

the sector operator's task was similar at the two VTSs. Whereas at VTSNY each sector operator had but one radar screen to monitor, at VTSPS each operator had to observe three or more radars. The South Sector operator clearly had the heaviest workload of the three, since that sector had five radar screens, a Radar Digitized Display System (RDDS), and two CCTV systems to monitor. This sector handled approximately twice as many participating vessels and consequently had twice as many radio communications as each of the other two sectors. As with the other two sectors, South Sector did not have full radar coverage and so had to additionally employ the Vessel Movement Reporting System, an extra burden for the operators. South Sector had the lowest frequency of Discretionary Activities and the highest subjective workload ratings of any sector at either VTS.

The Activity Log results show that most of the sector operator's activities at VTSPS consist of monitoring and adjusting the Radar, conducting Vessel Communications, and Working with VDCs. The multidimensional scaling analysis suggests that while the latter two are critical tasks, the Radar activities are not. A large number of vessels in a sector is associated with high frequencies of Vessel Communications and Working with VDCs, and a higher rating of Subjective Workload. Further details and implications of these results will be discussed in Section 5.

5.0 MAJOR FINDINGS AND THEIR IMPLICATIONS

5.1 MAJOR VARIABLES AND OBSERVED SECTOR PATTERNS

While the stated objective of the study was the identification of the major determiners of sector operator workload, the data collection and analysis reported to this point have presented a complex picture of a very complex task. Further analyses were necessary to identify the major variables that relate to operator workload and explore the nature of their contributions.

A selection of variables is presented in Table 5-1, where they serve to summarize the major findings. The values shown are either taken from Tables 3-1 and 4-1 or are calculated from those values. The first block summarizes conditions in the five sectors -- two at VTSNY and three at VTSPS -- that were examined in the study. "Sector" as represented by the columns of the table is the traditional radar sector(s) monitored by one individual. The number assigned to each such sector by its Vessel Traffic Center (VTC) appears at the top of each column. Other measures were explored as quantitative replacements for the radar sectors. Some of these are also included in the table, as follows. Sector miles is the cumulative total of the high volume mileage. Mean number of VDCs represents the number of participating vessels in a sector during the sessions observed. VDCs per sector mile represents the density of traffic in a sector.

The second block in the table summarizes the high-frequency components measured by the Activity Log: Radar Monitoring, Working with VDCs (writing, filing, etc.), Looking at VDCs (presumably a monitoring activity), and Vessel Communication (observable transmitting or listening). The third block summarizes the recorded Transmissions. Values there represent the means over sessions of: the number of Operator-initiated Transmissions, the number of Vessel-initiated Transmissions, the time in seconds on the air, and the percent of time on the air. The fourth block presents the Communications per VDC. This measure is assumed to represent the complexity of the traffic information that must be communicated in a sector. The last row is a measure of the operator's Subjective rating of perceived Workload. The conspicuously large values for each variable are emphasized in bold type.

A number of important relationships are summarized in this table. The two VTSNY sectors have a relatively small mileage and a small-to-moderate number of participating vessels. The special density of VTSNY is described by its high values for VDCs-per-Sector-Mile. VTSNY has a moderate level of operator activity and of communications. The relatively high Communications-per-VDC

Table 5-1

Summary of Major Variables over Five Sectors

	NEW YORK		PUGET SOUND		
	(1) Mariners Harbor	(3) UpperBay & Ambrose Ch	(1) Strait	(2) North	(3) South &DpSouth
HARBOR/SECTOR CHARACTERISTICS					
Sector Miles	14	43	**423**	**508**	**351**
Mean # VDCs	7.7	12	14.5	14.4	**33.1**
Mean # VDCs/ Sector Mile	**0.55**	**0.28**	0.03	0.03	0.09
REAL-TIME ACTIVITIES (ACTIVITY LOG: mean freq per half-hour observation)					
Radar Monitor	23	36	37	26	30
Working VDCs	22	27	16	19	27
Looking VDCs	6	4	7	8	14
Vessel Comm	15	20	17	19	**37**
RADIO COMMUNICATIONS (RECORDINGS: mean value per half-hour observation)					
Oper Trans	22	43	26	26	**63**
Vessel Trans	27	54	26	28	**72**
Time Seconds	154	303	169	199	**499**
Time Percent	9	17	9	11	**28**
RADIO COMMUNICATIONS PER VESSEL DATA CARD					
OpTrans/VDC	**2.83**	**3.57**	1.79	1.81	1.90
VessTrans/VDC	**3.53**	**4.46**	1.79	1.94	2.18
Seconds/VDC	**20.00**	**25.25**	11.66	13.82	15.08
Percent/VDC	**1.10**	**1.40**	0.65	0.77	0.84
Subjective Workload	33	47	39	48	**70**

Note: Any discrepancies in ratios are the result of rounding after calculations.

values are compatible with the greater complexity and number of projected meetings, crossings, etc. that must be communicated at VTSNY. The density and complexity of VTSNY conditions do not translate into a high Subjective Workload. The first two VTSPS sectors, Strait and North, have extremely large mileage, moderate numbers of participating vessel, and moderate levels of operator activity. Their conspicuously high mileage does not translate into a high subjective workload. The last sector, VTSPS's South/Deep South, has a relatively high mileage and a conspicuously high number of VDCs, or participating vessels. This high number of VDCs is associated with high values for communications measures, and a conspicuously-high Subjective Workload. This comparison of conditions and subjective workload across the observed sectors is compatible with the view in the VTS community that the VTSPS South Sector (here including the Deep South Sector) is especially difficult for the operator. Overall, the observed patterns suggest that density or complexity of traffic or many miles to scan are not principal determiners of operator workload. **The observed patterns suggest the hypothesis that the major determiners of operator workload are the number of participating vessels and the immediately associated communications.**

5.2 PATH ANALYSIS OF THE SECTOR OPERATOR'S TASK USING VTS NEW YORK DATA

To explore further the relationships among the major variables and to test the hypothesis that the number of participating vessels and the associated communications are the major determiners of operator workload, a "path analysis" of the operator's task was done, first using the VTSNY data and then, to test the generality of the results, using the VTSPS data. This analysis was done by procedures described in Reis, 1982; Kerlinger and Pedhazur, 1973; and Kenny, 1979. The general logic was to select a set of related variables, to hypothesize a pattern of "paths" among them, and to calculate the strength and significance of the links. Using the standardized regression model (Neter, Wasserman, and Kutner, 1989), each variable beyond the first was regressed on the variables that lead into it. The intention was to distribute the observed effects among the available, relevant links. Based on the statistical results, the paths were refined or revised. The hypothesis above would be supported if the links from Number of VDCs to Communications to Subjective Workload were strong and significant.

The resulting VTSNY path diagram is illustrated in Figure 5-1. Assuming that time or "causality" moves from left to right, the first variables presented are the major harbor factors. Sector is here represented by its VTC-assigned radar sector number. The potential replacements for this number, shown in Table 3-1, were examined in preliminary path analyses and found

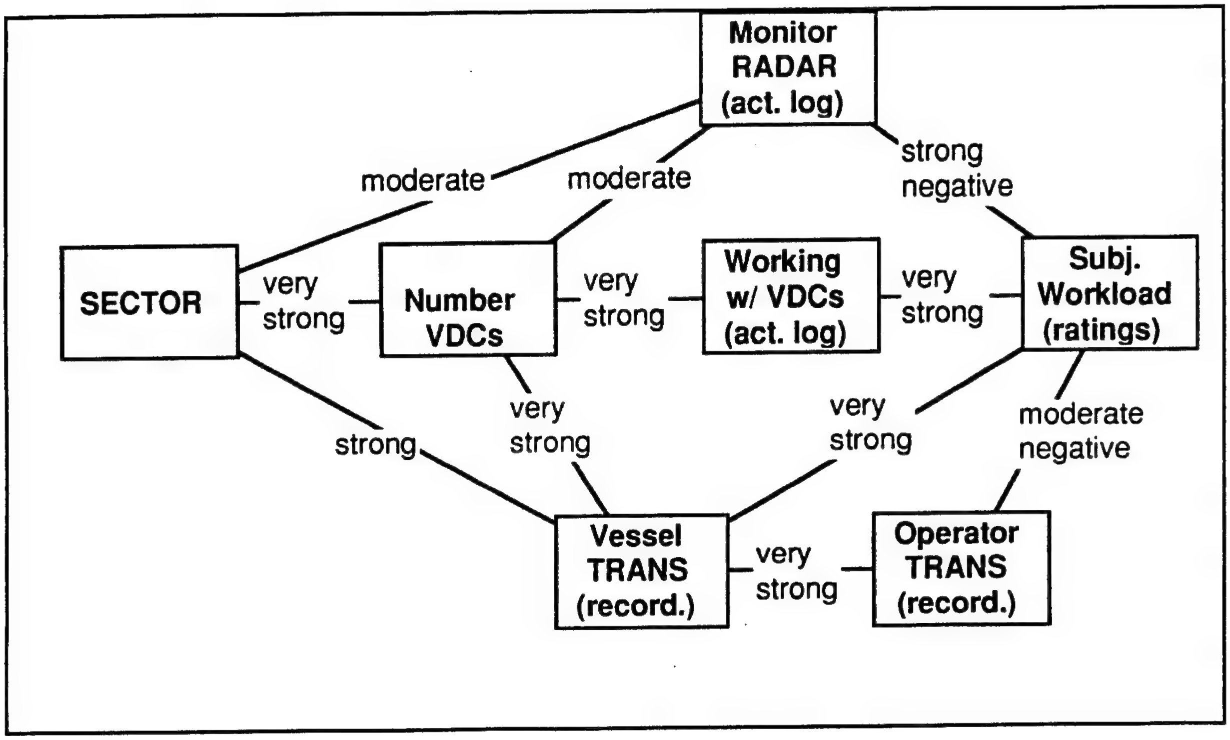


Figure 5-1. Path analysis of VTS New York data.

to be less highly related to other variables than the categorical radar sector. The sector is a very important factor in the number of VDCs that can be expected in a session, and that link is shown in the diagram.

The major tasks represented are Radar and Working with VDCs, which are taken from the Activity Log, and Vessel Radio Transmissions and Operator Radio Transmissions, which are taken from the accompanying recordings. The last box is the operator's rating of Subjective Workload. Data included here represent those sessions for which Activity Logs, recordings, and subjective ratings were all available. Sample size is 18 for the first four measures, and 17 for Vessel Radio Transmissions, Operator Radio Transmissions, and Subjective Workload. The relative strengths and significance levels of the links are represented in the diagram by verbal labels.

1. Harbor Factors and the Operator's Task. Of primary interest were the relative magnitude of effects of the Harbor Factors, Sector and Number of VDCs, on each of the major tasks. Both Sector and Number of VDCs had effects on all operator tasks. The strongest effects were those of Number of VDCs on Working with VDCs and on Vessel Radio Transmissions. The links from the

Harbor Factors to Radar are weaker than those to the other Tasks. One possible explanation for the weakness of the effects on Radar is that this activity is, indeed, less determined by measured harbor factors than it is initiated by the operator.

2. Major Tasks and Operator's Perceived Subjective Workload. The diagram also illustrates the relative effects of each of the included tasks on Subjective Workload. The strongest effects on Subjective Workload were those of Working with VDCs and Vessel Radio Transmissions. The observed relations between Radar and Subjective Workload and between Operator Radio Transmissions and Subjective Workload were weaker and negative. One possible explanation for the observed pattern of relationships is that Working with VDCs and, most especially, Vessel Radio Transmissions are the least discretionary tasks and, thus, the most disruptive to the operator. When total task workload in a condition increased, the operators decreased attention to the tasks over which they had more discretion, Radar and Operator-initiated Radio Transmissions, to compensate. In operator terms, "When things get crazy, you give half advisories."

3. Harbor Factors and Operator's Perceived Subjective Workload. The path analysis technique allows the calculation of the indirect paths from Harbor Factors through the Tasks to Subjective Workload. To do this, the coefficients produced by multiple regression are assumed to approximate partial correlations and the several coefficients along the path of interest are multiplied to provide a coefficient for that path. These values are not represented in the diagram. The indirect effects of Number of VDCs, along all possible paths to Subjective Workload, were generally stronger than the indirect effects of Sector on Subjective Workload. Comparison of the effects of the indirect effects of Harbor Factors and the direct effects of Tasks on Subjective Workload showed that the effects of the Harbor Factors were weaker than the effects of the Tasks.

5.3 PATH ANALYSIS OF THE SECTOR OPERATOR'S TASK USING VTS PUGET SOUND DATA

The primary objective of a second path analysis, done using the VTSPS data, was a test of the generality of the VTSNY findings. Some of the same general effects as in the VTSNY path analysis are apparent, but there are some differences. At VTSNY, "Sector," as a categorical variable, represented two geographical areas that were relatively similar in conditions and that set relatively similar requirements on the operators. The VTSNY pattern was relatively straight-forward. At VTSPS, the three sectors were quite different in their conditions, in the component activities, and in the requirements that they imposed on the operator. The relevance of some of these differences among the sectors to the path analysis is discussed below.

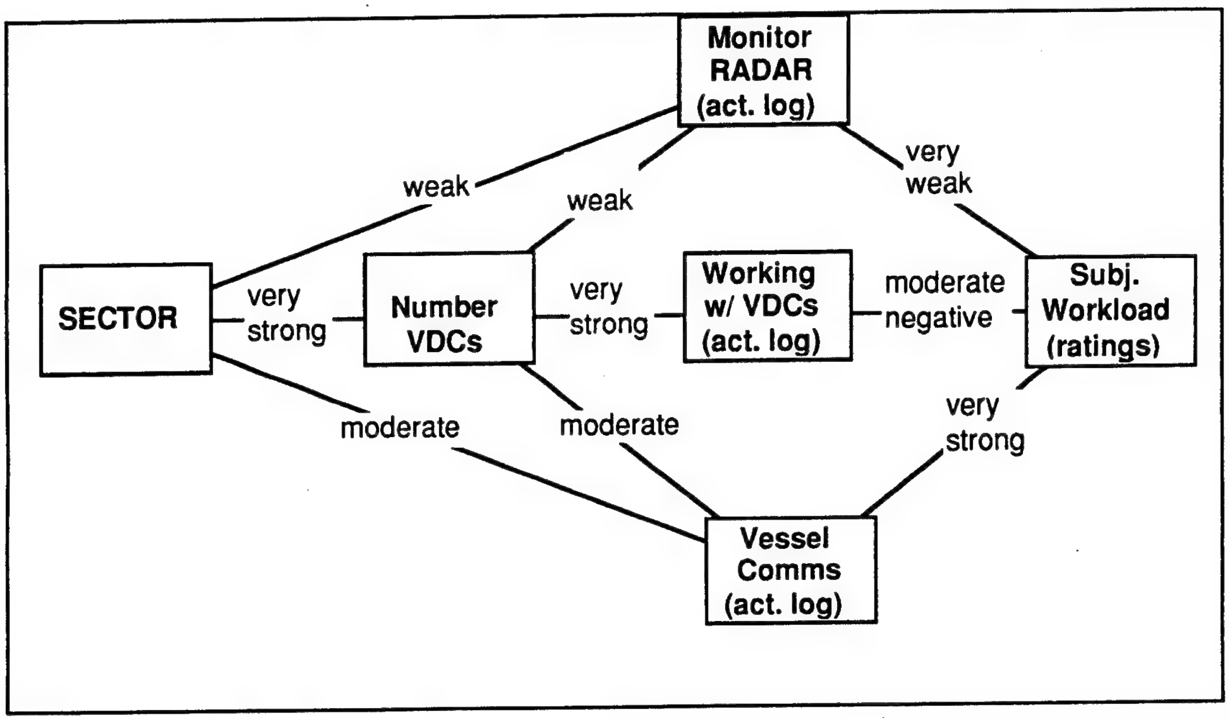


Figure 5-2. Path analysis of VTS Puget Sound data.

The resulting VTSPS path diagram is illustrated in Figure 5-2. Sector (represented by the VTC station number), Number of VDCs, Radar, and Working with VDCs are the same variables used for the VTSNY analysis. Vessel Communications, from the Activity Log, has been substituted for Vessel and Operator Radio Transmissions from the recorded communications. This substitution was made because the arbitrary division made between Vessel Radio Transmissions from the Strait and North Sectors (described in Section 4.1.1) resulted in spuriously high values in correlations and in path calculations. What is lost is the distinction between Vessel- and Operator-initiated Transmissions. The measure of Subjective Workload used here is the Mental Demand sub-scale of the NASA TLX. The sample size for the effects shown was 39 for the earlier links in the diagram and 23 for the links converging on Subjective Workload.

1. Harbor Factors and the Operator's Task. As was the case at VTSNY, both Sector and Number of VDCs had effects on all operator tasks. At VTSPS, Sector had an even stronger effect on Number of VDCs than was the case at VTSNY. This stronger effect was the result of the South Sector's consistently greater number of VDCs than the other two sectors. As was the case at VTSNY, Number of

VDCs strongly effected Working with VDCs, an effect quite apparent in Table 5-1.

The effects of Sector and Number of VDCs on Vessel Communications are more complex at VTSPS than they were at VTSNY. The South Sector with the high number of VDCs, showed higher values for Vessel Communications, but the other sectors had communications problems independent of the sheer numbers of vessels. The Strait Sector operator could spend the better part of the half-hour observation period trying to communicate with one non-English speaker. The North Sector operator needed to monitor by radio communications those vessels that were not in range of any radar. The Strait and North Sector operators shared a common channel, resulting in competition for access. All sectors had difficulties with poor transmission conditions. The contributions of these other conditions have added sufficient variability to the data to weaken the calculated links from Sector and Number of VDCs to Communications from what they were at VTSNY.

2. Major Tasks and Operator's Perceived Subjective Workload. The diagram also illustrates the relative effects of each of the included tasks on Subjective Workload. The difficulties of Vessel Communications at VTSPS are reflected in their conspicuous effect on subjective ratings of Workload. The negative link from working with VDCs suggests that even that relatively non-discretionary task is less of a contributor to workload when there is high communications activity. Such an effect was not seen at VTSNY.

3. Harbor Factors and Operator's Perceived Subjective Workload. The relative strength of indirect paths from Harbor Factors through Tasks to Subjective Workload were also calculated (but not represented in the diagram). The indirect effects of both Sector and Number of VDCs on Subjective Workload were greatest when they were measured through Vessel Communications. Indirect effects were also apparent through Working with VDCs. As was the case at VTSNY, the direct effects of tasks on Subjective Workload were greater than the indirect effects of Harbor Factors.

5.4 SUMMARY OF MAJOR FINDINGS AND THEIR IMPLICATIONS

The following summary emphasizes the results of the VTSNY path analysis. This emphasis is based on the conclusions: first, that VTSNY's pattern is the more general of the two and, second, that the VTSPS path analysis, despite its greater complexity, supports rather than conflicts with the VTSNY findings.

1. Harbor factors. Sector, represented by the VTC-assigned number of the radar sector, had effects on all major tasks and on the operator's subjective perceptions of the Workload of a

session. From the present findings, it is not clear which sector characteristics actually caused the observed effects. Number of VDCs had stronger effects. Of the tasks, the most strongly affected were Working with VDCs and Vessel-initiated Transmissions, those tasks requiring immediate attention to participating vessels.

The implications are that any change in number of participating vessels would have effects on the operator. Those effects would be strongest on tasks requiring immediate attention to participating vessels.

2. Working with VDCs and Vessel Radio Transmissions. Of the operator's tasks, working with VDCs and Vessel Radio Transmissions are affected most strongly by number of VDCs and, in turn, affect perceived Workload. From these findings, it can be inferred that the requirement to react to vessels, rather than to initiate the interactions, makes a greater contribution to the operator's perceived workload. (Such an inference is consistent with the operator workload literature reviewed by Huey and Wickens, 1993.)

The implications are that successful automation of these functions would have the greatest overall benefits on the sector operator's workload. Such automation appears possible in the near term. The VTS Upgrade, introduced in Section 1.2.2, is intended to automate the VDC function. The engineering potential now exists for vessels to automatically transmit much of the information that now is transmitted by verbal radio communication.

3. Operator radio transmissions: Operator-initiated Radio Transmissions were very strongly affected by Vessel-initiated Radio Transmissions, but had only weak effects on perceived Workload. Apparently, operators are able to moderate this task and corresponding perceived workload, possibly by variations in the timing and content of transmissions.

The implication of the strong control of operator action by vessel radio transmissions is that automation of that function would have positive effects on operator radio transmissions, even without the latter's automation.

4. Radar. Radar monitoring, as measured in this study, was moderately affected by harbor factors, either sector characteristics or number of participating vessels. Presumably, this means that radar monitoring was done more at the discretion of the operator than were other tasks. In addition, the path diagram shows a negative relation between radar monitoring and workload. This means that when the number of VDCs, working with VDCs, and related vessel radio transmissions were low, radar monitoring made relatively more of a contribution to workload.

When number of VDCs, working with VDCs, and vessel radio transmissions was high, radar monitoring made relatively less of a contribution.

The implications are that the automation of at least some aspects of other tasks would allow more frequent radar monitoring, even without any automation of that task.

5. Harbor factors versus tasks. Comparison of the effects of harbor factors and of tasks on perceived workload shows that the effects of the harbor factors are weaker than the direct effects of the Tasks.

The implication of the greater effects of task is that changes in task design, including automation, could potentially have greater effects on the operator than changes in such harbor conditions as sector characteristics or number of participating vessels. This potential means that successful automation of some of the operator's responsibilities could compensate for some increased Sector demands or number of participating vessels. On the other hand, it also means that "clumsy" automation (Wiener, 1989) has the potential to increase the operator's workload.

6.0 CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

6.1 OBSERVED BEHAVIOR OF THE VTS SECTOR OPERATOR AND ITS IMPLICATIONS

In Section 1.4 it was suggested that the objective of this study might be viewed as discovering how the VTS sector operator distributed finite cognitive resources among task components. The data collected here and their analyses provide some insight. The breakdown into percentages of time spent showed highest percentages at both VTSNY and VTSPS spent on the major activities: first, radar monitoring, and then vessel communications and working with VDCs. At both VTSs, much smaller percentages of time were spent on "discretionary" or "other" communications and activities. At VTSPS with its greater number of task components and with the very high communications load in the South Sector, a smaller percentage of time was spent on discretionary components than at VTSNY. Correlation matrices found that discretionary activities were negatively correlated with the major activities, suggesting that as the major activities in a particular session demanded more time and effort, discretionary activities decreased. The percentage of time spent in discretionary activities could be viewed as a measure of spare capacity or a reserve available for difficult or emergency conditions.

A more important finding is that some aspects of the major activities can be discretionary also. Activities that consistently increased with number of participating vessels were responses to vessel-initiated communications and VDC-related activities. At VTSNY, with its moderate number of vessels, radar monitoring also increased with these other activities and was correlated with them. At VTSPS, especially in the South Sector with its high number of participating vessels, radar monitoring did not show such a pattern. It did not increase proportionally to the number of vessels or to the communications and VDC activity, and was not highly correlated with them. While the experienced operator does not need to monitor the radar constantly, the South Sector pattern of increased communications, increased VDC-related activities, and no increase in radar monitoring suggests a high workload and a loss of discretionary capacity. The very high subjective workload ratings from the operators at this sector reinforce this interpretation.

That vessel communications are dominant and that monitoring will be reduced to accommodate them, is supported by the findings of a previous study of the VTS watchstander (Devoe et al., 1979). This study investigated watchstanders, who were working with earlier technology, and found that as "traffic load" increased, "time allocation" to "communications with vessels" and "tracking" increased and time allocation to "monitoring" and to "miscellaneous" decreased. Their cautions seem appropriate here:

that operating without "residual time" means an inability to respond adequately to emergencies, that loss of monitoring means a potential loss to all VTS functions, and that, with computer-based systems, loss of monitoring means an uncritical dependence on the computer. The general assumption that workload is related to VTS operator performance and VTS system performance underlies the following discussion and seems compatible with the concerns expressed by the VTS community.

Recommendation Number 1: Any planning, design, or evaluation of the VTS operator's task should have as an objective an effective, but not excessive, use of the individual's time, attention, and cognitive capacity. After any changes are made to the operator's responsibilities, the effects should be re-evaluated.

6.2 HARBOR FACTORS AS DETERMINERS OF THE SECTOR OPERATOR'S WORKLOAD

The harbor factors, conditions in the AOR over which the VTS has relatively little control, were assumed to be major determiners of operator workload. "Sector" has traditionally been defined as a radar sector to be monitored on a radar scope(s) by one operator. The sector, identified by its VTC-assigned number, has the advantage of representing a consistent set of conditions: for example, a geographic area, a certain mileage of high-volume traffic lanes or customary vessel tracks, an expected number of vessels per unit time, an expected density of vessels per mile, a pattern of track convergence, etc. However, a continuous, quantitative variable would be more effective for data analysis and for the management of operator workload. Several alternatives were considered during the data analysis. Mileage or vessels per mile were not effectively related to operator activities or subjective workload. Places of track convergence were suggested by watchstanders as factors in both VTSs. As examples: at VTSNY, points of entrance to or exit from Kill Van Kull; at VTSPS, places where ferries crossed at right angles to the main traffic lanes. However, the effects of such locations could not be measured by the methodology of the present study. Number of vessels per unit time in a sector was the major determiner of operator activity and workload and is emphasized through out this report as a separate variable. The categorical variable of radar Sector has been retained and is presented in the analyses shown. The analyses showed that Sector had effects on all major task activities and on the operator's subjective ratings of workload. However, it is not certain which specific sector characteristics were responsible for the observed effects.

Recommendation Number 2: When a new system is in place with the capability of recording and plotting vessel transits, the issue of "places of track convergence" (or congested areas) should be re-examined. Plotted overlays of tracks

monitored by an operator in a unit of time will identify those places. Sector boundaries should be located to distribute these places among the operators and these sector configurations should be evaluated for their effects on workload and situational awareness. The record keeping capabilities of the new system will allow further investigation of other harbor factors as well.

Number of participating vessels had stronger effects than Sector. Of the task activities affected, the most strongly affected were those that were immediate responses to the number of vessels: working with VDCs and attending to vessel-initiated transmissions. The implications of these findings are that any changes in number of participating vessels would have effects on the operator. If number of vessels were to be increased in a harbor, the sector operator's workload might be kept manageable by reducing the size of the sector assigned to a single operator, by re-distributing some of the associated activities to other individuals, or by automating some of those activities.

Recommendation Number 3: Any increase in number of participating vessels in a harbor should be accompanied by an evaluation of the effects of these increases on the sector operator's workload. If the effect is a substantial increase, changes in task design should be introduced to offset the increase. Options are changes in sector size, re-distribution of some activities to other individuals, or automation of some activities.

6.3 TASK ACTIVITIES AS DETERMINERS OF THE SECTOR OPERATOR'S WORKLOAD

This study of the complex task of the sector operator was begun with the consideration of as many of the activities described in the Standard Operating Procedures for each VTS as: 1) needed to be performed in real-time and 2) could be readily observed. Throughout the data collection and the data analysis, the list was shortened to include only the most major activities. Those that consistently played a significant part in both VTSs and in every analysis were: radar monitoring, working with VDCs, and communicating with vessels. Analyses revealed characteristics of these activities that have general implications for VTS issues.

1. Working with VDCs and vessel-initiated transmissions. Of the sector operator's activities, reacting to vessel-initiated transmissions and working with VDCs had the strongest consequences in operator-reported subjective workload. Apparently, these activities allowed the operators little discretion; instead they needed to respond, and respond promptly, to the vessels. Such a finding is consistent with the human

factors literature that finds tasks over which the individual has little control are perceived as most demanding (Huey and Wickens, 1993; Wickens, 1984). The implication of this finding is that the automation of these two activities would have the most immediate benefits for the sector operator.

Recommendation Number 4: Among the operator's activities, the highest priority for automation or redistribution should be given to responding to vessel-initiated transmissions and to keeping vessel transit records.

2. Operator-initiated transmissions. Operator-initiated transmissions were strongly affected by vessel-initiated transmissions but had only a moderate, negative effect on perceived subjective workload. Apparently, operators were able to limit this activity when necessary, possibly by variations in the timing and content of their transmissions. Indeed, one operator told a researcher, "When things get crazy, you give half advisories." Delay and reductions are appropriate mechanisms to enable the operator to respond to a high level of incoming transmissions, but they may also be an indication of an approach to the limit of discretionary capacity.

The findings of the study suggest several approaches to increasing the time for advisories. Automation of this activity or some of its components is a possibility. For example, routine OPNOTES could be automatically broadcast to vessels in an area without the immediate involvement of the operator, leaving time for communications that must be customized to a particular vessel. Alternatively, the observed interdependence among the activities suggests that automating the more demanding activities, working with vessel data cards and responding to vessel-initiated transmissions, would benefit the advisories indirectly.

Recommendation Number 5: Consideration should be given to automatic broadcasting of the more routine operational notices and advisories.

3. Radar monitoring. Radar monitoring, as measured in this study, was very weakly related to harbor factors, either sector or number of participating vessels. Presumably, this means that radar monitoring was done more at the discretion of the operator than were other activities. In addition, some of the analyses found an inverse relationship between radar monitoring and subjective workload. This may mean that when overall task workload was low, the operator watched the radar more frequently; when workload was high, the operator took attention away from this relatively discretionary task to attend to more demanding tasks. Some aspects of radar monitoring or some of its components might be automated. In the short term, the simplest mechanism to improve radar monitoring would be the automation of

the less discretionary activities. Operator-initiated radar monitoring should be the indirect beneficiary.

Recommendation Number 6: Consideration should be given, but with a lower priority, to the automation of some components of radar monitoring. Examples are alarms when acquired targets approach each other or approach designated dangers.

4. Harbor factors versus activities. Comparison of the effects of harbor factors and of task activities on subjective workload showed that the effects of the task activities were greater. The implication of this finding is that changes in task design, including automation, could potentially have greater effects on the operator than changes in such harbor conditions as sector or number of participating vessels. This potential means that successful automation of some of the operator's responsibilities could compensate for some increases in sector demand or number of participating vessels. On the other hand, it also means that "clumsy" automation (Wiener, 1989), requiring additional, new activities, has the potential to increase the operator's workload.

Recommendation Number 7: Increases in responsibility for the VTS sector operator, such as increase in sector size or in number of participating vessels, should be carefully balanced against the demands imposed by task or equipment design.

6.4 IMPLICATIONS FOR VTS ISSUES

A number of VTS issues, considered in the design of this study and in the analysis of the data, were presented in Section 1.3. The implications of the findings for those issues are as follows.

1. A starting concern presented by the U.S. Coast Guard Program Office (G-NVT) was the appropriate "definition of a sector."

The findings strongly suggest that the primary factor to consider in defining a sector is the number of participating vessels in a unit of time. Exactly how many participating vessels can be handled by an individual operator will depend on many factors, but most especially on the effort to be expended in creating and maintaining a record of each one's transit and in communicating with each one. There are trade-offs among these three major factors: more vessels could be handled by an operator if less effort needed to be expended on the associated activities.

2. Given the identification of the important factors to consider in defining a sector, what is the appropriate amount of responsibility for an individual operator?

For the harbor conditions, and the task and equipment configurations observed at VTSNY and VTSPS in 1993, the best estimate of an appropriate number of vessels for one operator comes from an inspection of the data in Table 5-1. Comparing conditions and subjective ratings of workload across sectors with a range of workloads, a mean of 14 vessels seems to be a frequent value and 33, for the South Sector at VTSPS, seems to be a conspicuously high value. This high number of vessels was associated with a mean of at least 40 instances of working with or looking at the VDCs in a half hour and a mean of 135 vessel- or operator-initiated transmissions in that time. This rate of activity was also associated with a conspicuously high rating of subjective workload. A reasonable inference from these comparisons is that the load of 33 vessels should be reduced to near the 14 found in the other sectors. These numbers are for conditions similar to those observed in the study; substantial differences in harbor conditions or task and equipment designs may mean higher or lower numbers can be handled by a single operator.

VTSPS's mechanisms for moderating the workload in the South Sector are compatible with the findings here. Their short-term solution was to assign a second operator when needed to fill out the VDCs for the first, who communicated with the vessels. As a longer-term solution, they have documented a need for, and received, sufficient billets to split the sector.

Recommendation Number 8: With harbor conditions and task and equipment design like that observed in NY and PS, an attempt should be made to keep the number of vessels monitored by a single operator not much higher than 14 in a half hour. When the Upgrade is well established in NY and/or PS, workload should be re-evaluated with the new equipment. New activity and subjective workload levels can be evaluated by comparison to that measured with the baseline equipment and the baseline 14 vessels.

3. A major concern for the both the near term and for the long term development of VTS was the best use of automation or technology to moderate the workload of the VTS operator and to improve the quality of the service to the primary customer, the mariner.

Automation would allow a number of other mechanisms for moderating the effects of a large number of participating vessels. Focusing directly on the number of participating vessels as the important factor, an automated system could keep track of the number of vessels per sector and recommend an early

hand-off point from the more busy to the less busy sector. In other words, the geographic boundaries of the "sector" could be dynamic. In the past, VTSNY treated Kill Van Kull in an analogous manner, associating more or less of it with either of the two major sectors, depending on conditions. During the testing of the VTS Upgrade at VTSNY, the operators took advantage of the easy communications between consoles to initiate early hand-offs from the busy Upper Bay Sector to the less busy Newark Bay Sector. When the disparity in number of vessels is too great to be remedied by varying the boundaries, an automated system might recommend the location of a temporary split of the busy sector. Care needs to be taken that new sector boundaries, that do not correspond to radio channel boundaries, do not cause confusion in communications.

Recommendation Number 9: The design of new equipment should include a "dynamic sector" that would recommend or allow changes in sector boundaries. Boundary considerations should be traffic density, places of track convergence (see Recommendation Number 2), and radio channel boundaries.

Focusing on the workload involved in creating and maintaining the vessel information, one possibility would be to automate this process so that it takes very little operator time or attention. Some basic concepts of the Upgrade, accessing an existing data base to complete the electronic "VDC" and automatic tracking of the vessel, by dead reckoning, radar, or Global Positioning System (GPS), have this intent. Refining the automation of this function is probably the simplest and most straight-forward mechanism for affecting the sector operator's workload and performance within the present general concept of VTS. Another possibility is to assign a second operator to perform the VDC function for the primary sector operator. During the VTSNY testing of the Upgrade, this was another use of the linkage between consoles.

4. The nature of communications between the sector operator and the vessel, the primary function of VTS, is a major issue (Sanquist, et al., 1993). Recent developing technology in Automatic Dependent Surveillance (ADS) has increased interest in the types of information that might productively be automated.

The (expected) finding of the importance of communications in the sector operator's workload supports the above concern and suggests that focusing on the automation of the communications would be an effective approach to manipulating the workload and task design. The VTS Upgrade as presently installed at VTSNY and as planned for VTSPS, does not change the way communications with vessels are done. A possible first step would be the transmission by vessels, or even some vessels, of their initial position and of sufficient vessel information to automatically initiate and complete the "VDC." This change would immediately

reduce the workload of the two most demanding activities, creating the VDC and communicating with vessels. Research on the human factors aspects of communications was proposed in the Human Factors Plan for Maritime Safety (Sanquist, et al., 1993). This study would require the examination of the needs and capabilities of both the VTS sector operator and the mariner. It would also require the consideration of the state of technology for the GPS, ADS, and the shipboard Electronic Chart Display and Information System (ECDIS).

Recommendation Number 10: Given the central role of communications in the VTS function, continuous attention should be given to the communication needs of the VTS operator and of the mariner, and to the developing technologies available to serve those needs.

5. At the beginning of this study, VTS New York expressed concern with the potential effects on operator workload of increases in the Area of Responsibility (AOR) or the number of vessels required to participate.

The findings strongly suggest that an increase in the number of participating vessels, with no changes in other harbor conditions or in equipment or task design, would greatly increase the operator workload. Increases in the AOR, with no changes in equipment or task design or number of operators, would have some effects. The magnitude of the effects resulting from increased AOR would depend on how many additional vessels, how many additional communications, etc., were associated with that increased area. As of this writing in the Fall of 1994, there is a prospective change in Federal Regulations to decrease the minimum size of vessels required to participate from 300 gross tons to 40 meters. For VTSNY, this will mean the addition of a sufficient number of lite ("lite" meaning without a tow) tugs and small ferries to add approximately 500 vessels to their past average of 600 vessels per day. Without compensating changes in the VTSNY operation, the effect on workload should be substantial. Nearly doubling the number of vessels would mean that the number per half hour at VTSNY would approximate the conspicuously high mean of 33 per half hour observed in VTSPS's South Sector, where it was associated with a very high rating of subjective workload. Such an increase in the number of participating vessels must be balanced against the demands of equipment and task design (Recommendation 7).

6. VTS Puget Sound expressed a concern that a major component of the sector operator's task, radio communications with vessels, was complicated by the large area and poor radio transmissions in some parts of the AOR. These difficulties make necessary frequent searches through several radio sites in order to communicate with a given vessels and these searches potentially affect workload.

The study provides some relevant data. The activity log mean frequencies for "Adjusting Comm Controls," summarized in Tables 3-1 and 4-1, show that VTSPS did not adjust comms controls more frequently than did VTSNY. The absolute frequency was not high in either VTS. For VTSPS, the correlation between this activity and ratings of subjective workload for a session were not significant. However, the checklist, asking the operators to rate the importance of a particular activity to a session, revealed high mean values for this activity in the North and South Sectors. In addition, the questionnaire for VTSPS asking for further comments included, "Comms were really bad today." The inconsistency between the observations in the activity log and the reports in the checklist and questionnaire suggests that any searches take too short a time during a half hour to influence the activity log frequencies or the means of these frequencies over a number of sessions, but that they are sufficiently frustrating to the operator to be influence his/her reported reaction to a session. For those cases, consideration should be given to automating this search and allowing the operator to concentrate on the content of the transmission rather than its mechanics.

Recommendation Number 11: For PS, with its large area and relatively poor radio transmissions, consideration should be given to an automatic process to find the best site to communicate with each vessel.

6.5 OBSERVATIONS ON ADDITIONAL VTS ISSUES

1. Special considerations for radar monitoring. Given the technical approach of this study, with its emphasis on the analysis of the observable workload, radar monitoring has been left to the "discretion of the operator" and the mercy of other task demands. However, there has been an underlying assumption here, an assumption apparently shared with the VTS community, that radar monitoring is an observable indicator of the operator's cognitive efforts, when he or she switches from gathering, logging, maintaining information, to analyzing, integrating, predicting the situation in the waterway. It is this analysis of the traffic situation that produces advisories, the service to the mariner. The introduction of the VTS Upgrade presents major changes in the visual display. An analysis of the design and use of visual displays is a complex problem beyond the scope of the present study but some central aspects of the Upgrade will have quite important effects on how "radar" monitoring is done.

The findings of this study show a competition between activities associated with gathering and maintaining information and those associated with analyzing it. One major information gathering/maintaining function of the operator using the older technology was the tracking of a vessel's progress through the

AOR by recording the location and times of its communications on the VDC. A major function of the new VTS Upgrade is the replacement of the tracking of vessel by communications and VDC with a completely different technology. The Upgrade automates this tracking function with an "icon" on the screen representing each participating vessel. The icon represents the automatic recording of the progress of the vessel, either by tracking a radar target or by "Estimated Positioning" (EP), dead reckoning using inputs by the operator. This automation was intended to leave the operator free to monitor the larger traffic situation. As of Fall 1994, the radar tracking was not working smoothly, leaving the operator with the new responsibility of monitoring the system's success in tracking each vessel, a gathering/ maintaining function. This responsibility means a resulting increase in workload and in time and attention taken away from monitoring traffic, an analyzing function. While the effectiveness of operator performance was not measured in this study, the situation of poor updating of vessel position is analogous to that observed in simulator analyses of mariner's use of electronic systems for navigation in harbor traffic. Those analyses found that the results of noise or failures in the automatic positioning of own ship was both increased workload and decreased overall performance (Smith et al., 1994; Smith & Mandler, 1993). All the components of an integrated system must work smoothly for its potential to be realized.

Recommendation Number 12: A high priority should be given to correcting the functioning of the Upgrade's automatic tracking system.

A major difference between the older and newer technologies for "radar" monitoring is in the treatment of the geographic size of the AOR. The traditional radar technology required that each radar site in the harbor be represented by one radar scope, which meant that areas large enough to need additional sites also needed additional scopes. For the operator this meant that the scopes to be monitored mapped the entire area covered by radar. The Upgrade is designed to present each operator with a constant two 24-inch screens for all graphic and alphanumeric information functions. The geographic area is mapped by a series of "windows" that integrate electronic charts with the radar targets from the area covered. These windows can be manipulated and overlaid in various ways to fit the available screen size. Targets on windows that are not visible to the operator are "monitored" by the system using pre-set alarms for closest point of approach (CPA), traffic lanes, etc. VTSNY, with its relatively small AOR, is not providing a demanding test of this new technology. The operators are able to arrange windows to observe the entire area as they did before. Indeed, the Upgrade with its EP function gives VTSNY a new capability, the "observation" of radar blind spots.

VTSPS, with its many times larger area, promises a much more demanding test of the new treatment. With the traditional radar technology, each VTSPS operator has multiple scopes to observe the area covered by multiple radar sites. With the Upgrade (not yet operational at VTSPS as of this writing), each "sector" will be covered by multiple windows, overlaid on each other on the two screens in a very different arrangement than before. The human factors literature warns of the dangers of operators' losing their place in multiple windows, especially in times of high workload (Woods et al., 1991; Woods, 1987). VTSPS operators' use of windows and alarms for monitoring of the AOR should be examined to provide recommendations for the design of future installations of integrated systems for VTS 2000. Potential human operator consequences involve not only workload, but also "situational awareness," the degree to which there is an accurate perception of the factors and conditions that are affecting the operation (Sarter & Woods, 1991). Both concepts have obvious consequences for VTS effectiveness.

Recommendation Number 13: With the installation of the Upgrade, the VTS operator's use of this new system should be evaluated for "situational awareness" as well as workload. VTSPS, with its large area to be monitored, has a special need for such an evaluation.

2. Workplace design and operator workload. During the study, VTS personnel expressed a variety of opinions as to the effects of such workplace factors as the proximity or accessibility of operators to each other and to the watch officer/supervisor, the exposure of real-time operators to outsiders, ambient light, noise, and temperature, etc. While such factors were not a priority of this study, the data contain some small evidence of their effects. The activity log data, summarized in Table 3-1 for VTSNY and 4-1 for VTSPS, contain frequencies for both "Professional Communications" and "Extraneous Communications." At VTSNY, the Upper Bay Sector had a lower incidence of both types of communications, suggesting that the frequencies for both activities are (negatively) influenced by workload.

VTSPS, with three sectors, shows the apparent influence of an additional factor. The North Sector has a higher incidence of both types of communications than the other two sectors. That its incidence is higher than the high-workload South Sector suggests the operation of the same effect observed at VTSNY. Why the North Sector has a higher incidence of both types of internal communications than the Strait Sector with comparable workload is less obvious. One possible explanation is in the physical layout of the VTSPS VTC. Compared to the Strait Sector console, the North Sector console is centrally located, convenient not only to both other Sector consoles, but also to the watch officer/supervisor console and to any visitors talking to anyone else in the VTC. Further support for the existence of such a

mechanism appeared in the checklist on contributors to workload. Additional items not shown in Table 4-3 included "noise in VTC." The mean ratings were: Strait, 1.50; North, 2.29; and South, 1.18. Apparently, the central location for North Sector operator meant that he/she not only contributed more to the noise but also suffered more from it.

The effects of physical proximity should be considered in the planning of the layout of the VTCs. But note that these effects may change with the introduction of the integrated Upgrade: in an early examination of VTSNY's use of this system, one of its advantages described by the operators was the capability for internal communications, which both allowed an operator to ask for information or help from any other watchstander and shielded the operator from noise in the VTC. Such effects are a simple illustration of the potential vulnerability of the real-time operator-in-the-loop to the characteristics of task and equipment design and of the care that must be taken in any new development.

Recommendation Number 14: Physical layout of the new TSCs should be planned and evaluated with consideration of both necessary physical proximity and protection from noise and disturbance.

6.6 SUMMARY OF CONCLUSIONS

1. Harbor factors. The harbor factor with the greatest effect on the VTS sector operator's workload was the number of participating vessels. Geographical area, mileage of high volume traffic lanes, and density of vessels per mile had little systematic effect. The effect of degree of traffic convergence was not measured.

2. Task activities. The VTS sector operator distributes time and attention, first, to responding to vessel-initiated transmissions and to recording the transmitted information received from the vessels. He/she gives second priority to self-initiated monitoring of traffic on radar and transmission of advisories. When workload is very high, radar monitoring is reduced, suggesting a potential reduction in situational awareness.

3. Implications. The study findings revealed dynamic relations among harbor and task factors and suggested the potential results of any changes in those factors. An increased number of vessels would have major effects; increased sector area would have effects to the extent that it was accompanied by additional vessels. Reductions in the effort of responding to vessel-initiated transmissions or to the recording of data would reduce total workload. Potentially, this reduction would increase the frequency of operator-initiated transmissions and radar

monitoring of traffic. On the other hand, increased effort in recording and maintaining data would increase the total workload and reduce the frequency of operator initiated activities. The dominant tasks deserve priority in introducing automation, but at the same time require special care in the design and evaluation of that automation.

7.0 A QUICK LOOK AT VTS NEW YORK'S USE OF THE UPGRADE

7.1 INTRODUCTION AND OBJECTIVES

The primary objective of the larger study was the identification of the factors that determine the sector operator's workload, factors described in the general conclusions in Section 6.0. The operator's task is described as dominated by vessel communications and by the immediate response to those communications in recording and maintaining the vessel information. Radar monitoring was interpreted as the most readily observed indication of the operator's efforts to analyze, interpret, and predict the traffic situation in preparation for advisories to the mariner. These advisories are the product that the VTS real-time operator-in-the-loop provides to the real-time mariner-in-the-loop during a transit of the AOR. Unfortunately for the quality of this service, systematic observations of the sector operator demonstrated that this radar monitoring was reduced when the workload of vessel communications and vessel information was high. The conclusions suggested that automation for these two demanding activities would free operator capacity to increase radar monitoring, and, presumably to analyze the traffic situation, rather than merely to record it.

The VTS Upgrade, introduced in Section 1.2.2, is the integration of remote sensors, data base systems, and operator displays. The operator works with one console upon which he or she can control integrated radar and chart views of the harbor sector, video views from closed circuit television, communication controls, and windows presenting alphanumeric vessel information. The following discussion of the investigation contains sufficient description of important features to support the points made. The reader interested in a detailed description of the Upgrade is directed to the following relevant manuals: VTSNY Standard Operating Procedures (Commanding Officer, VTS New York, 1994a), Operational Training Guide (Commanding Officer, VTS New York, 1994b), and the Software User's Manual for the Coast Guard Vessel Traffic Service System (Commandant, U.S. Coast Guard, 1994).

With the Upgrade, the major activity of vessel communications remains very much as it was before: communications controls are operated from the console but all <u>vessel communications</u> are done by voice, one vessel at a time. The vessel information and tracking activities were formerly handled by each vessel's reporting its particulars and its progress by voice communications, and by the operator's responding and making a hand notation of each communication on a Vessel Data Card (VDC). A very central function of the Upgrade is the automation of <u>vessel information and tracking</u>. With the Upgrade, when a vessel makes its "initial call," the operator retrieves its record from the computerized data base and begins the automatic tracking of the vessel, using either radar or an

"Estimated Positioning" (EP) feature. The operator must watch the display screen to monitor the success of this process at the same time as he or she is doing "radar monitoring" of the on-going situation.

As a part of the investigation of the VTS sector operator's workload, the human factors team returned to VTSNY to examine the operators' use of the Upgrade. One objective was to test the generality of the techniques and assumptions of the primary investigation by their application to operations with a substantially different equipment suite. A second and more immediate objective was to examine the new system and to make recommendations as to how it could be improved. In keeping with the conclusion in Section 6.4, that automation of the vessel information and tracking functions had the potential to decrease workload and increase operator monitoring of the traffic situation, special attention was given to these processes.

7.2 APPROACH

Observations were made on 23 and 24 August 1994, during the final testing of the Upgrade. On those days, the watch section being observed was communicating with traffic, using the Upgrade (in Building 108), while a second watch section was doing "parallel operations" on the earlier system (in Building 400) and sharing control of the radar. The observed operators were fully trained on the Upgrade but had very little operational experience on it. Because modifications were still being made to the Upgrade and because the operators had so little experience with it, any comparisons between performance on the earlier system as a baseline and on the Upgrade must be regarded as tentative. On the other hand, these data do identify the most conspicuous strengths and weaknesses of the Upgrade at a time when it is still in development.

The approach was very much as described in Section 2.0. All available manuals on the Upgrade were examined to develop a new Activity Log and Questionnaire. These materials were applied during preliminary observations at VTSNY and modified as needed. The recordings of the radio communications were not examined. Because these data are not representative of the final ongoing operation with this equipment, only a minimum of data analysis was done. Only descriptive statistics are presented below.

7.3 PRINCIPAL FINDINGS

7.3.1 Observational Data on Early Use of the Upgrade

The sector previously referred to as Mariners Harbor was now termed Newark Bay/Kill Van Kull, and what had been previously termed Upper Bay was now Upper Bay/Ambrose Channel. Data were collected during 12 half-hour observation periods on the Newark

Bay/Kill Van Kull Sector and during 11 of those periods on the Upper Bay/Ambrose Channel Sector. The observation periods spanned various times during the two days. The mean frequency of each measure was calculated for each sector and the results are presented in Table 7-1.

Table 7-1

VTS New York Upgrade Measures

	Newark Bay/ Kill Van Kull	Upper Bay/ Ambrose Ch.	% of Total (Combined)
#VDCs	7.4	11.4	
Displays			
EP/Radar Track	53.7	61.8	36.9
Prospective List	12.9	13.1	8.3
VDC Window	7.4	9.7	5.4
Other	6.8	8.1	4.8
CCTV	5.1	7.8	4.1
Vessel Comms	16.5	27.0	13.8
Prof. Comms	16.9	14.5	10.1
Touch Panels	4.9	8.2	4.1
Keyboard	9.4	8.9	5.9
Other	4.9	3.6	2.6
Discretionary	9.3	2.8	4.0

The number of VDCs in each sector was very similar to that noted during observations of the previous VTS system, with Upper Bay/Ambrose Channel Sector handling about 50% more traffic than the other sector. The measures listed in Table 7-1 generally reflect this greater activity for the Upper Bay/Ambrose Channel Sector. Discretionary Activities, a combination of communications and other activity, were markedly lower than previously, suggesting that with a similar vessel traffic load, much less time was available for such activities.

Because the Upgrade equipment is quite different from the earlier system, some activity measures appear different. Estimated Position/Radar Track is the most comparable activity to radar monitoring. This activity had a substantially higher frequency than that measured in the earlier system, and, for both sectors combined, comprised 36.9% of the activities, compared with 23.5% previously.

Rather than using hard copy vessel data cards, the Upgrade system primarily uses computerized displays. Several activities go to make up what we formerly referred to as Working with VDCs and Looking at VDCs. These include accessing the data base by calling up displays of the Prospective List of vessels as well as a VDC Window. Associated activities include use of the Keyboard, for entering information, and approximately one-half of the activities listed in Table 7-1 as Other. Among other things, this last was composed of working with Dock/Anchor/Exit AOR display screens or writing down pertinent information received from vessels for subsequent entry into the VDC Window display. These total approximately 23% of the activities, similar to that obtained with the earlier system.

7.3.2 Comparison to Baseline VTS New York Operation

Table 7-2, showing selected performance with the two suites of equipment, provides some perspective. The similarity in mean number of VDCs observed with the two sets of equipment, approximately seven for Newark Bay and 12 for UpperBay/Ambrose, suggests that any differences in observed performance are a function of VTS operations and equipment, rather than of transient harbor conditions. The exact tasks to be performed by the operator are different with the two systems, but an attempt is made here to equate them.

Table 7-2

Selected Comparisons of Percentage of Total Activities for Baseline and Upgrade

Measure	Equipment	
	Baseline	Upgrade
Monitor/Track	**24**	**37**
Vessel Information	**23**	**23**
CCTV	14	4
Vessel Comms	14	14
Professional Comms	8	10
Discretionary Activ.	15	4

The performance measure shown is the percentage of total observed activities represented by the labeled activity. The percentages are taken from Table 3-1 for the baseline system and Table 7-1 for the Upgrade. Within those tables, the percentages total 100%. Only selected activities are included here. "Monitor/Track" is a comparison of radar monitoring as a percentage of total operator activity on the earlier system and a

composite of analogous responsibilities with the Upgrade. The Upgrade is intended to automatically create a record of each transit by recording the track of an "icon" on the screen as a vessel moves through the AOR. The operator must make initial actions to arrange this for each vessel and then ensure that the icon either tracks the radar target or stays with the approximate position of the vessel, using "Estimated Positioning" (EP) based on dead reckoning with operator-entered information. During the August observations, the radar was not working smoothly, requiring either frequent correction of that tracking by the operator or a change, by operator action, to an EP track, with the subsequent maintenance of that track. In addition to these arrangements and frequent corrections to the tracking of all vessels in the sector, the operator was monitoring the traffic situation as had been done using the earlier, baseline system.

The combined vessel tracking/radar monitoring function increased from 24% of the total activities using the earlier equipment to 37% using the Upgrade. This increase was the most conspicuous change from the baseline to the Upgrade system. Since the findings of the larger study demonstrated that radar monitoring, in the sense of analyzing the traffic situation, decreased when workload was high, the observed increase in monitoring and tracking as percentage of total activities can be attributed to the creation and maintenance of the tracks. This is an undesirable result, assuming that the increased effort in an information production responsibility is detracting from the operator capacity available for the understanding, analyzing, and predicting the traffic situation and is eliminating any reserve capacity to respond to an extraordinarily high traffic load or to emergencies. Some proportion of this increase in effort for vessel tracking may be very transient, affected by difficulties during the August testing in sharing radar control between the two parallel systems. But there are generally acknowledged shortcomings to the radar processor in use at VTSNY. A different radar processor, expected to be more effective, is planned for VTSPS's Upgrade installation and for eventual installation at VTSNY. The effectiveness of these new processors must be evaluated in these installations. Because of the importance of the tracking/monitoring function to the sector operator's responsibility, the Upgrade is only as capable as this sub-system.

Vessel information is represented by VDC-related activities on the baseline system (see Section 3.1.2, Table 3-1) and by the total of the following analogous activities on the Upgrade: Entry P-list, Retrieval P-list, VDC window, Dock/Anchor/Exit AOR, Sector Summary, Key board, and Note pad. The Upgrade has not changed the total vessel information function as a percentage of total activities: it remains at 23%.

Activities that have not been very much affected by the Upgrade are included here to provide a context. Closed circuit television (CCTV) has decreased: from 14 versus four percent. This decrease may be favorable, if the operator needs less information from the CCTV, or unfavorable, if the decrease is an indication of less time available for monitoring. Vessel Communications (both vessel- and operator-initiated) have not changed, as would be expected from the similarity in Number of VDCs. Professional Communications have increased slightly, from eight to 10 percent, although this increase may be temporary. During this testing session there was considerable discussion in the VTC about the functioning of the system and changeover in the radar control, discussions that will probably not continue when Upgrade use becomes routine. As noted above, discretionary activities have decreased, an expected outcome if required tasks have increased.

7.4 RESULTS OF THE OPERATOR QUESTIONNAIRE

7.4.1 Operator's Subjective Rating of Workload

A questionnaire was administered to each operator as he or she rotated to his or her break. The first item on the questionnaire asked for a simple, overall rating of the extent of operator workload (OWL) on a scale from zero (very low) to 100 (very high), for the session just completed. The mean ratings, with a comparison to the baseline system, are as follows:

Sector:	Newark Bay	UpperBay/Ambrose
Baseline System:	33	47
Upgrade:	**54**	**75**

The Upgrade results are higher than the mean ratings given for a session on the baseline system. Note that, using the Upgrade, the mean rating for UpperBay/Ambrose Channel was at the level of the Puget Sound's South Sector in the earlier observations. This is an increase from a moderate to a high subjective rating. See Table 5-1 for those comparative data.

7.4.2 Contributors to Workload

To help identify the items contributing to the high Upgrade rating, the questionnaire included a long list of specific features of the Upgrade, taken primarily from the "Operational Training Guide (Commanding Officer, VTS New York, 1994b). This approach was an attempt to separate activities that are not apparently different to the research observer: as an example, EP and radar tracking. The operator was asked to rate each listed item as to the extent that it contributed to the total workload rating for the session. Rating choices were as follows:

R - reduced workload
0 - not relevant or no effect
1 - minor contribution
2 - significant contribution
3 - major contribution
4 - interfered with other tasks
5 - required assistance

The results are summarized in Table 7-3. The first column is a brief description of a task or responsibility. The second column is the number of cases that contributed to the mean of the ratings. The mean and standard deviation follow in the next two columns. The last two columns are the number of times an item was indicated to have reduced workload (R), to have interfered with other responsibilities (4), or to have caused the operator to require assistance from the supervisor or another operator (5). Items with a mean rating of 2 (significant contribution) or more are indicated by bold type.

Overall, these ratings are consistent with the Activity Log findings. Major functions of the Upgrade, both the adjusting and monitoring of both EP and radar tracking, were rated to make "significant contribution" to workload. Entry P-list and create vessels, additional major functions of the Upgrade, made significant contributions to workload and provided the most incidents of interference and requirements of assistance. "Taking notes (paper)" is an additional indication of the difficulties with initial calls: when the operator could not enter data quickly enough to keep up with incoming calls, he or she resorted to writing down the information and then typing it as a separate operation.

New Upgrade features that were selected as having reduced the workload (R) were the Sector Summary and the internal communications. The Sector Summary is a window that lists the tracked vessels in the sector along with operator-selected information, such as: name, type, speed, course, radar, track status, and destination. According to the operators, this list provided an important resource for understanding and predicting the traffic situation. Internal communications allow the operator to talk over his or her headset to any other operator or to the supervisor. (Note that the August observations were during testing of the system and that there was more happening in the VTC than would be expected in routine operations.) These two features were identified again in the written comments on the questionnaire, which are described below.

This style of questionnaire was not used during the data collection on the baseline system, therefore, no comparison of measures is possible. However, some of the functions that are essentially unchanged by the Upgrade were included to provide

Table 7-3

Summary of Rated Contributors to Workload

TASK/RESPONSIBILITY	COUNT	MEAN	SD	#R	#4,#5
monitoring radar tracking	**19**	**2.05**	**1.31**		**2**
adjusting radar tracking	**20**	**2.10**	**1.37**		**2**
using radar controls	20	2.10	1.37		2
monitoring EP tracking	**20**	**2.20**	**1.11**		**3**
adjusting EP tracking	**20**	**2.35**	**1.14**		**3**
monitoring CCTV	17	1.35	0.70	2	
Touch Panel, camera	19	1.37	0.90		1
Touch Panel, VCR	19	0.32	0.75		1
vessel-initiated calls	**20**	**2.45**	**1.23**		**3**
operator-initiated calls	**20**	**2.30**	**1.26**		**2**
Orion Panel, radio selection	20	1.00	1.12		2
Touch Panel, radio adjustmnt	20	1.05	1.00		2
Entry-P-list, initial call	**20**	**2.40**	**1.35**		**5**
create vessel, initial call	**20**	**2.45**	**1.15**		**4**
Vessel Selection Window	20	1.85	1.14		2
reviewing VDCs	18	1.22	0.55	1	
Hand-offs	19	1.21	0.71	1	
Violations	20	0.40	0.60		
Docking a vessel	20	1.45	1.39		3
Anchoring a vessel	20	0.55	0.89		
checking vessel out of AOR	19	1.53	1.39	1	3
manipulate charts/overlays	20	0.90	1.29		1
using Command Status Window	20	0.30	0.47		
using Sector Summary	18	1.78	1.31	2	4
using OPNOTES log	20	0.30	0.47		
using OPNOTES cards	20	0.30	0.47		
using OPNOTES icons	17	0.59	0.51		
Passdown, Trouble Logs	20	0.25	0.44		
taking notes (paper)	**18**	**2.00**	**1.46**	**2**	**3**
filling out paper forms	20	0.10	0.31		
internal VTC comms, events	19	1.00	0.67	1	

some context. Vessel- and Operator-initiated calls made significant contributions (means of 2.45 and 2.30, respectively), as would be expected from the general findings of the larger study. These values for the major activities of vessel communications, activities that have always been major VTS

functions, were equaled by all the tracking and initial information functions of the Upgrade (means of 2 or more). This match provides some perspective as to how major these new activities were in their contribution to operator workload.

7.4.3 Summary of Operator Comments

Sector operators with even a minimum experience on the Upgrade are now the most appropriate "subject matter experts" on its "operability." To allow this study to benefit from their expertise, the questionnaire asked for comments about features that had made a positive contribution to the observed session. They were also asked to comment on features that were difficult to use and to suggest modifications that might improve these. While the questionnaire asked for comments relevant to the just observed session, many took the opportunity to comment more broadly on their experience with the new system.

Generally, Upgrade features mentioned as having made a positive contribution to their last session were computer-based capabilities not possible with any other approach: that a large database can be accessed, that a track record can be maintained, that communicating consoles allow operators to act as a team, etc. A composite list of features follows.

- Completes entry from partial name. When operator types in name of communicating vessel, the rest of the information is provided from the database.

- OPNOTES icons to cue operator. Icons on the chart presentation remind the operator to "pass" a relevant operational notice to the transiting mariner. This notice is a major contribution of VTS to the mariner.

- Sector Summary useful. (See 7.4.2 above.)

- Takes away load at end of day. Formerly, required summary reports were done manually.

- Potential that will track vessel. A major, promised function of the Upgrade was the automatic radar tracking of the vessel. As of the reported observations, the radar feature was not functioning smoothly. The most frequent comment from the operators was the anticipation of the ultimate, successful implementation of this function. (See discussions in Section 6.5 and 7.3 above.)

- EP track, even over blind spots. The Upgrade provides for an estimated position track to maintain a vessel's recorded track in a radar blind spot. This feature provided a selectable substitute for the radar tracking during the operations.

o Vessel name by track plot is good. A label is provided by each vessel's icon.

o Automatic time stamps on track. A selectable label is provided by each vessel's icon.

o Can take information for other operators. The inter-connected consoles allow operators to respond to initial calls and create a vessel record for another operator. This feature provides a mechanism for sharing the workload. (See Table 7-3.)

o Internal comms, can ask for help, keeps out background noise. (See Table 7-3.)

o Challenging, hi-tech, fun!

The questionnaire concluded by asking the operator to comment on features that had especially contributed to their workload in the just completed session and on how system could be modified to solve the problem. The features mentioned were, of course, quite redundant with those identified as contributors in Table 7-3 above and do not need to be repeated here. The most frequent modifications suggested to solve those problems are summarized below.

o Trusting that new radar processor will solve tracking problems. The most-frequently mentioned modification was a fully-capable, smoothly-functioning radar processor. This change was not considered merely a desirable improvement but an absolute requirement.

o Name/destination on icon. More information than just the vessel name was wanted as a label for the icon. While all needed information was available on the Sector Summary (as described in Section 7.3 above) that Summary was on a separate screen and window from the vessel icon and the on-going traffic situation.

o Respond to initial call with fewer steps.
o Update vessel with fewer steps.
o Vessel out of system with fewer steps. (These last three are information creation/maintenance functions. The general findings of this study support a prediction that less effort on these processes should increase the operator time and capacity spent on analysis and prediction.)

7.5 CONCLUSIONS ON THE EARLY USE OF THE UPGRADE

7.5.1 Potential Contributions of Integration and Automation

The major, potential contributions of the Upgrade, as a more fully integrated and automated system than the VTSNY baseline equipment suite, are in functions that cannot be achieved any other way: that a large database can be accessed, that a track record can be created and maintained, and that communicating consoles enhance the ability of watchstanders to share workload as a team. The positive potential of these capabilities was understood and appreciated by the sector operators and was apparent in their discussion and responses to the questionnaires. However, the potential positive contributions were not yet observable in their vessel information and tracking activities. **As a general conclusion, the Upgrade had not reduced the total effort of the vessel information function and had introduced new tracking difficulties that complicated the process of traffic monitoring.**

7.5.2 Effectiveness of Vessel Information Functions

As of the August 1994 observations, the Upgrade had not reduced the total vessel information activity from what it had been with the VTSNY baseline equipment suite and the manual VDCs: these activities remained at 23% of the operator's total activities. To make better use of the Upgrade's potential for reducing the workload of creating and maintaining vessel information, the subject matter experts on the operability of the Upgrade, the sector operators, recommend the capability:

- to respond to an initial call with fewer steps
- to update vessel status with fewer steps
- to get a vessel out of the system with fewer steps.

7.5.3 Effectiveness of Vessel Tracking

The combined vessel tracking/radar monitoring function increased from 24% of total activities using the earlier equipment to 37% using Upgrade. This increase was the most conspicuous change from the baseline to the Upgrade system. The composition of this increase requires some interpretation. If the increase were in radar monitoring in the sense of analyzing and predicting the traffic situation, the outcome would be desirable; if the increase were the result of new requirements to maintain the automated tracking function, the outcome would be undesirable. Since the findings of the larger study demonstrated that radar monitoring, in the sense of analyzing the traffic situation, decreased when workload was high, the observed increase in monitoring and tracking as percentage of total

activities can be attributed to the creation and maintenance of the tracks. That this was the case is supported by the high ratings of "adjusting" radar and EP tracking as contributors to workload (in Table 7-3), by responses to questionnaires (summarized in Section 7.4.3), and by spontaneous discussion during the data collection period. This increased effort is an undesirable result, assuming that the increased effort in an information production responsibility is detracting from the operator capacity available for the understanding, analyzing, and predicting the traffic situation and is eliminating any reserve capacity to respond to an extraordinarily high traffic load or to emergencies.

Some proportion of this increase may be very transient, affected by difficulties during the August testing in sharing radar control between the two parallel systems. But there are generally-acknowledged short-comings to the radar processor in use at VTSNY. A different radar processor is planned for VTSPS's Upgrade installation and for eventual installation at VTSNY. The effectiveness of these new processors must be evaluated. Because of the importance of the tracking/monitoring function to the sector operator's responsibility, the Upgrade is only as capable this sub-system.

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